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ABSTRACT

The world faces two converging crises, a lack of biological literacy and a rapid increase in environmental degradation. In order to insure a secure and safe environment for future generations of organisms, all humans must be taught the basic biological and physical processes that sustain life. This project seeks to fill the chasm in the general public understanding by improving the quality of biological systematics taught in schools. The following chapters provide guidelines for developing school curriculum in biological systematics: (1) "Why Teach Order and Diversity in the Living World?"; (2) "What Questions Do Systematists Ask?"; and (3) "The Goals of Education in Systematics." Included are sample instructional activities for students ages 6-18. (ZWH)

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Order & Diversity in the Living World: *Teaching Taxonomy & Systematics in Schools*

by Jorge V. Crisci,
Joseph D. McInerney &
Patricia J. McWethy

The Commission for Biological Education of the International Union of Biological Sciences In Cooperation with UNESCO

Order & Diversity in the Living World: *Teaching Taxonomy & Systematics in Schools*

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4

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Preface

"The laws of biology are written in the language of diversity."
E. O. Wilson (1989)

Homo sapiens is by nature a classifying animal. Our continued existence depends on our ability to recognize similarities and differences between objects and events in our physical universe and to communicate these similarities and differences linguistically. Indeed, the very development of the human mind is closely related to the perception of discontinuities in nature.

Even before the advent of *Homo sapiens*, classificatory ability was probably an important component of fitness in animal evolution. Regardless of whether behavior is learned or instinctive, animals must be able to perceive similarities in stimuli for survival. Thus, the ability to recognize similarities in patterns of sensory input is probably as old as the earliest forms of sensory perception in living animals (Crisci 1977).

Although the *science* of classification dates back to the writings of the ancient Greeks, discussion of principles and procedures in classification has occurred only recently (Raven et al. 1971; Sokal 1974). Biology plays a central role in this discussion for two reasons:

1. A reasonable estimate of the number of species on Earth falls somewhere between 5 and 30 million, of which scientists have described at some level only about 1.5 million. For more than 99 percent of the described species, we know nothing more than a few morphological facts and have identified only one to several localities where they occur.

2. Proper species classification is important because a species is not like a molecule or a cloud of molecules, but rather is a unique population of organisms, the terminus of a lineage that split off from the most closely related species thousands or even millions of years ago. Species have been shaped into their present forms by mutations and natural selection, during which certain genetic combinations survived and reproduced differentially out of an almost inconceivable larger total. No two species, no matter how closely related, are any more interchangeable than are two Mozart sonatas. Each species is incredibly rich in genetic information.

In 1989, in recognition of the importance of systematics, the Commission for Biological Education (CBE) of the International Union of Biological Sciences (IUBS) initiated a project on education in biological systematics. The Commission adopted this project following the recommendation of the 1988 General Assembly of the IUBS (Canberra, Australia) as one way to help improve the quality of biological systematics taught in schools. Inherent in this project is a consensus that all students need to learn more

biological systematics, and that instruction in biological systematics must be revised significantly from the way it has been traditionally taught.

This document, the product of the Commission's efforts on this project, intends to:

1. Create a coherent vision of what it means to be literate in systematics in a world where biological diversity is treated as a global resource to be indexed, used and above all preserved; and in a world where systematics provides the framework for analyzing biological diversity and putting such knowledge into a more accessible form.

2. Establish a set of standards to guide the revision of school curriculum in biological systematics.

3. Provide examples of classroom instruction that are consistent with the aforementioned standards, that address systematics and biodiversity, and that can be adapted to meet the needs of teachers and students around the world.

Table of Contents

Principal Authors & Contributors....iii

Contributors & Acknowledgments....iv

Preface....v

I. Why Teach Order & Diversity in the Living World?....1

A. The Current Social Context for Teaching Systematics....1

B. Why We Should Value Biodiversity....1

C. Why We Should Value Systematics....5

D. Systematics & the Nature of Scientific Inquiry....7

II. What Questions Do Systematists Ask?....9

A. What Is the Current State of Biological Diversity?....9

B. What Is the Current Rate of Extinction?....11

C. How Can We Organize Life's Diversity?....13

III. The Goals of Education in Systematics....16

A. The Need for a New Approach To Teaching Systematics....17

B. Curriculum Standards....17

C. Sample Instructional Activities....19

IV. Glossary....21

V. References....22

VI. Appendix....28

A. Sample Instructional Activities for Ages 6-12....30

1. Magnet Mystery....32

2. Going To Bat for Animals....40

B. Sample Instructional Activities for Ages 13-18....46

1. The "Musical" Method of Teaching Classification....48

2. The Nuts & Bolts of Classification....52

3. Dichotomous Keys....56

4. Constructing Dichotomous Keys....60

5. Classifying Plants & Animals in a Public School....64

6. Phylogeny: The Relationship Between Taxonomy & Evolution....68

7. Confusing Cats: The Florida Panther....72

8. Evolution Theory: Genetic Technology in Basic Research....78

Chapter I

I. WHY TEACH ORDER & DIVERSITY IN THE LIVING WORLD?

A. The Current Social Context for Teaching Systematics

The world faces two converging crises: a marked lack of biological literacy and a rapid increase in environmental degradation. Reversal of the latter crisis depends on remediation of the former, for unless the world's human inhabitants come to appreciate the basic biological and physical processes that sustain life, we are likely to continue those activities that have pervasive and irreversible negative consequences for the biosphere.

One may propose any number of conceptual frameworks for the improvement of biological literacy, and many such proposals now exist (Schaefer & Younès 1986; AAAS 1989; Rosen 1989; NRC 1990), reflecting diverse views about important concepts, teaching and learning, and the uses to which biological knowledge is put. No biological concept is more important, however, than biological diversity, which has been generated by 3.5 billion years of cumulative, iterative natural selection. All organisms share a single, complex, evolutionary history (Eldredge 1985), written in universal genetic material yet manifested in a stunning array of structures, functions and behaviors. These diverse organisms—in concert with abiotic factors—contribute to an interdependent biosphere, much as the individual instruments of an orchestra contribute to a symphonic whole; disruption of any one component reverberates throughout the system.

A basic understanding of biodiversity is central to an understanding of the living world and to making decisions about its healthy maintenance (Nicolis 1992). This assertion does not imply that the average school student or adult become a specialist in biodiversity and be familiar with an expansive number of organisms. Each person should, however, be familiar with the general range of biological diversity and the role that major groups of organisms play in the biosphere. In addition, each person should understand something about the interactions between living things and the abiotic world, and the ways in which those interactions affect our planet. These objectives require that one be able to derive some order from the seemingly infinite diversity of life on Earth, and that task brings one to the disciplines of taxonomy and systematics.

B. Why We Should Value Biodiversity

Biodiversity, as a property of living things and as a global resource, is important to humans for utilitarian, scientific, ethical and aesthetic reasons.

1. *Utilitarian reasons.* Biology education, at whatever level, should demonstrate the relationship of biological knowledge to personal, societal and global well-being and should acquaint students with the place of humans in the biosphere. Nations (1988), on whose work this section is based, states

that in modern society, the question seems to be: "What has biological diversity done for me lately?" The good news is that the answer to that question is: "Plenty, and more than you realize." Our lives are full of reasons to preserve the plants and animals that we depend upon as a species, and these reasons provide opportunities for classroom consideration of the importance of systematics to human health and welfare, and to the quality of life on our planet.

Our food is a good example. We eat a wealth of plants and animals in the home-cooked meals and restaurant dinners that we live on day-to-day. Yet one of the most immediate threats posed by the loss of biodiversity is the shrinkage of plant gene pools available to farmers and agricultural scientists. During the past several decades, we have increased our ability to produce large quantities of food, but we have simultaneously increased our dependence on just a few crops and our dependence on fewer types of those crops. As much as 80 percent of the world's food supply may be based on fewer than two dozen species of plants and animals (CEQ 1981). We are eroding the genetic diversity of the crops we increasingly depend upon, and we are eradicating the wild ancestors of those crops as we destroy wilderness habitats around the world.

We depend on biological diversity in ways less visible than the plants and animals we eat and wear, however. We also depend on them for raw materials and medicines, industrial fibers, gums, spice, dyes, resins, oils, lumber, cellulose and wood biomass. We screen wild plants chemically in search of new drugs that may be beneficial to humankind. Millions of dollars worth of medicinal plants are imported into the United States, where they are used to produce billions of dollars worth of medicines (OTA 1984).

We use animals in medical research as well. For instance, the United States imports tens of thousands of primates for drug-safety tests and drug production (OTA 1984). We use Texas armadillos in research on leprosy. Human activities that threaten the survival of these animals and their habitats threaten human welfare as well.

At the same time, we must acknowledge that we never will be able to demonstrate an immediate, utilitarian reason for preserving each species on Earth. Some may be of no use to humankind beyond their role in the great mystery of life. But who will tell us which species are unimportant? Who can tell us which level of extinction will seriously disrupt the web of life on which we depend?

Environmental writer Erik Eckholm (1978) says that one of the key tasks facing both scientists and governments is to identify and protect the species whose ecological functions are especially important to human societies. "In

the meantime," Eckholm continues, "prudence dictates giving existing organisms as much benefit of the doubt as possible."

One of the important factors in providing those species with the benefit of the doubt they deserve is educating ourselves and government policy makers about our dependence on biological diversity, and that education tends to emphasize the utilitarian value of species protection. One of the results is that there is a growing, pragmatic ethic among scientists and conservationists. It is an ethic that centers on the realization that our ability to preserve biological diversity depends on our ability to demonstrate the benefits that diversity brings to human beings (Fisher & Myers 1986).

On one level, these benefits take the form of immediate economic income through activities such as wildlife harvesting, tourism and maintenance of agricultural production. On another level, they focus on unfulfilled potential such as new crops, new medicines and new industrial products. Taken together, the benefits of biological diversity provide short-term income to individuals and improve the long-term well-being of our species as a whole.

These two levels of benefits work together because the prospects for long-term benefits of biological diversity depend on the immediate, short-term benefits to individuals. Little of the wild gene pool—the raw materials for future medicines, food and fuels—is likely to survive intact in places where people must struggle simply to provide their basic, daily needs (Wolf 1985).

One of our long-term goals as a species is to enjoy the uncounted benefits that our planet's biological diversity can eventually bring us. In the short term, however, for the next few decades at least, we must ensure that people receive material incentives that will allow them to prosper by protecting biological diversity rather than destroying it (Cartwright 1985).

2. *Scientific reasons.* The scientific value of biodiversity is related to the best knowledge that could result from its study. That means that the loss of species seriously affects our capacity to understand biological phenomena and processes. If the species are lost and the ecosystem where they reside is destroyed or specifically altered, our knowledge of the interrelationship among the species (phylogeny), the special relationships of species (biogeography), and the relationship between the species and their environment (ecology) will be forever incomplete. In addition, if we do not understand how the natural ecosystem functions, we will not be able to use our natural resources in a rational and sustainable way.

3. *Ethical reasons.* Why should we try to understand biological diversity? The scientific and utilitarian responses form only part of the answer to this and derivative questions such as whether we should try to preserve biodiversity. Biologist John A. Moore (1984) has written that, "Science can

tell us what we can (or cannot) do, but it is powerless to tell us what we *should* do." The answer to that question involves personal and societal values and brings us into the realm of ethics—the study of morality, the guiding principles that help us decide what is right and wrong, good and bad, moral and immoral.

We can propose various ethical justifications for maintaining biodiversity and, for example, for attempting to save endangered species:

a. **Economic justifications.** Humans can use species for many purposes—for food, fuel, clothing, shelter, entertainment, self-aggrandizement and medicine. Yet, economic value means more than the dollar value of a species. According to economist Alan Randall (1986), "The Earth's biota may be viewed as a resource. This view carries two immediate implications. First, (biologic) resources are instruments of human satisfaction, and second, they are scarce. Scarcity means that they are both valued and limited and that they can be increased only at the cost of foregoing something else that is valued."

According to Randall's definition, there is economic value in any species that is an instrument of human satisfaction. For example, a child might derive pleasure from watching a panda cub cavort with its parents in a zoo; the panda has an economic value. Similarly, we may gain satisfaction from cartoons of mutant turtles modeled after real-life species; these species have economic value.

b. **Justifications based on the intrinsic value of organisms.** Intrinsic justifications are based on the premise that species do not exist solely for human satisfaction; there need not be logical, practical or economic reasons for preserving species. As philosopher J.B. Callicott (1986) states, "Something is intrinsically valuable if it is valuable *in* and *for* itself—if its value is not derived from its utility, but is independent of any use or function it may have in relation to something or something else... an intrinsically valuable entity is said to be an 'end in itself,' not just a 'means' to another's end." In this sense, an African elephant would be valuable for its own sake, even if it existed in a world devoid of humans.

c. **Justifications based on the balance of nature.** Biologists recognize that all forms of life are interconnected. Removal of one species, just like removal of a single rivet from the wing of an aircraft, may not cause any harm. But as the number of such removals rises, the system, whether it be an ecosystem or an airplane, moves progressively closer to collapse. According to this reasoning, each species that exists has a value.

4. *Aesthetic reasons.* So far as we know, the ability to appreciate beauty—in all its manifestations and definition—is a uniquely human trait. This appreciation, broadly defined as aesthetics, certainly is central to the importance we attach to biological diversity, and our aesthetic appreciation of nature is enhanced by our understanding of nature's various components and their relationship to one another.

The aesthetic value of biological diversity may have as many definitions as there are people, and that value is inherent in activities ranging from bird watching and gardening, to art and music. People may derive their appreciation of nature's beauty from its parsimony or complexity, from the sheer power of certain predators or the elegance of their prey, from the fit of an organism with its environment, from the ability of microorganisms to inhabit the most inhospitable places, or even from an idea such as descent with modification, which helps us understand that all organisms are related and that the history of life on Earth is written in our genes.

As Paul Ehrlich (1988) points out, however, "There is an economic value to the appeal of other organisms. Birders buy binoculars and take expensive bird-watching expeditions; tropical fish fanciers buy aquaria and fishes; and dog and cat owners spend fortunes to feed their pets." It is not that easy, therefore, to separate our justifications for wishing to understand and protect biological diversity.

C. Why We Should Value Systematics

Few biologists appreciate fully the magnitude of the contributions made by systematics to basic biological research, yet these achievements are extraordinary indeed. The fundamental product of systematics, a classificatory system of living organisms, is an immensely useful system for information storage and retrieval. The work of morphologists, physiologists, ecologists, biogeographers, molecular biologists and others would be meaningless were it not for classification (Mayr 1969). As Simpson (1961) pointed out, "Systematics is at the same time the most elementary and the most inclusive part of biology; most elementary because organisms cannot be discussed or treated in a scientific way until some classification has been achieved, and most inclusive because systematics in its various guises and branches eventually gathers together, utilizes, summarizes and implements everything that is known about plants, animals and microorganisms, whether morphological, physiological, molecular, ecological or chemical."

The demand for the products of systematics is evident in several major and currently expanding fields (Haskell & Morgan 1988; Hawksworth & Bisby 1988) that encompass a wide range of subject areas in which systematics plays a critical and fundamental role. Although the relative importance of those fields will vary with circumstance and country, the last 20 years have focused both scientific and public attention on one pervasive issue: the environment, and more precisely, the increasing acceptance of the view that Earth is a habitat of finite resources. It is instructive to examine some of the more important fields related to systematics from this perspective.

1. *Conservation.* Knowledge of extant species is fundamental to discussions of conservation priorities. The massive growth of interest in conservation over the last 15 years has generated a demand for information on the occurrence and distribution of species.

2. *Environmental monitoring.* During the last decade, interest has in-

creased dramatically in the use of organisms as monitors of environmental change and contamination (Burton 1986; Woodwell 1988). The monitoring of environmental parameters requires an ability to recognize the organisms to be used as biomonitors, and in some cases those organizing monitoring schemes have had to devise their own identification aids (Mabey 1974).

3. *Agricultural and allied sciences.* The importance of the correct diagnosis of pests and diseases of agricultural crops is well established. Huxley (1934) was aware of this half a century ago, citing cases where incorrect diagnoses led to inappropriate actions. The literature on crop protection continues to be rich with such examples. For example, when the larger grain borer (*Prostephanus truncatus*) was introduced into East Africa from South America in 1976, it was assumed to be the lesser grain borer (*Rhyzopertha dominica*). Only in 1981, after it was well established and causing extensive damage, was *P. truncatus* correctly identified and the extent of the threat appreciated (Golob 1984). In Malaysia a report of the fungus (*Colletotrichum coffeanus*) that causes the coffee-berry disease proved to have been a misidentification for a tropical alga (Kang 1985).

With growing concern over the use of pesticides and herbicides, biological control of pests is assuming increasing importance in the tropics (Greathead 1984). Again, accurate identification is critical or biologists may seek natural enemies for the wrong pests, as in the case of mealy bugs on cassava (Cox & Williams 1981). Quarantine workers also require reliable diagnostic aids, and quarantine legislation depends on authoritative lists of names of prohibited organisms.

4. *Biotechnology.* Biotechnology, interpreted here as the use of living organisms in industrial processes, requires accurate identifications in the search for organisms that have novel or desired properties of experimental isolates. In addition, accurate identification helps in the recognition of contaminants.

Incorrect identification also can lead to expensive and time-consuming studies on material from the wrong species. Culture collections require strong systematic support in quality control to help avoid such occurrences. Culture collections provide an important living resource for biotechnology (Hawksworth 1985), and proper identification of strains has legal significance in patent decisions (Crespi 1985; Bousefield 1988).

5. *Geological prospecting.* Plant and animal materials form the principal sources of hydrocarbon energy: coal, oil and natural gas. A specialized, but economically significant branch of systematics involves the classification and identification of microfossils of significance in geological prospecting (Scott & Smith 1977). Geologists must be able to confirm which coal seams in a mine correspond to those in an adjacent work area or, similarly, plot the

extent of oil-bearing structures from exploratory bore holes. This can be achieved through highly developed systems of description, classification, and identification of plant pollen grains and spores and animal microfossils, particularly foraminifera, ostracods and conodonts.

D. Systematics & the Nature of Scientific Inquiry

Among the important objectives of science education is the students' introduction to the methods of science and to the habits of mind that scientific inquiry cultivates. The questions and methods of systematics provide numerous opportunities for students to encounter the nature of science—to see science as a unique and powerful form of inquiry that provides rational explanations for our observations about the natural world. The problems presented by biological classification are a case in point.

Classifications are not unique. Given any set of objects (or organisms), the logical requirements of a classification are fulfilled by an immense array of alternative solutions (Williams & Dale 1965). To use an analogy, if we wish to make a group of 10 students the subjects of a single dichotomous classification, we can divide the group into boys and girls, into those with musical talent and those who seem to be almost tone-deaf, into those living in the city and those living outside the city. Each of these classifications is valid, and each is optimal for a particular purpose but irrelevant for another.

It follows that the problem is not to classify, which is easy, but to find reasons for choosing a *particular* solution (classification) from among the many that present themselves. The choice rests essentially on that of *purpose*; whether a classification is right or wrong depends on whether it is or is not suitable to the purpose for which it has been constructed. It is possible, therefore, to arrange living things in numerous different classificatory systems, depending on which relationships one uses to construct the system. What then is the purpose of biological classification that guides our selection of a classificatory system?

Biological classification performs an essential function in information storage and retrieval. Classification should allow us to deal with a tremendous amount of data by subsuming a great deal of information into single words (the names of sets of organisms) so that we are not forced to deal simultaneously with all the data at hand.

Organization of data, however, is not the only function of biological classification, nor the only way in which systematics illustrates the methods of science for students. Classification systems also serve as scientific hypotheses about order in nature. These hypotheses, once tested and corroborated, permit us to study aspects of nature other than the attributes of organisms; for example, one may use classification as the basis for hypotheses about evolutionary relationships. The placement of genera and

species in higher categories also is significant for its predictive value with respect to physiological and ecological attributes, because species from the same genus, or genera in the same family, tend to have similar types of life histories, growth and behavioral characteristics, physiological responses, biochemical products, and host or substrate.

It is as hypotheses that classification schemes are ultimately useful, and it is in this sense that systematics serves to illustrate the methods of science in the biology classroom. The main purpose of biological classification is to generate hypotheses that have explanatory value. The "best" biological classification will suggest the most explanatory hypotheses. This is done by developing the most stable, robust and predictive classificatory system. A stable classification is undisturbed by addition of further information, is robust in that alteration to accommodate a small number of items, does not produce major changes in the classification and is predictive in that a property that exists in most members of a group will be expected to occur in those members not yet examined for it (Williams 1967). The tasks of systematics are to create such a general-purpose reference system and investigate the relations that extend from it to all other possible systems in biology (Hennig 1966).

The fundamental problem, therefore, is to develop a classification system that fulfills the requirements of stability, robustness and prediction. This system, in turn, should be based on an underlying process that generates the patterns we observe in nature. In living things, this process has two components:

1. The genetic relationships between organisms that arise through reproduction and that should play a major role in the delimitation of the species (Mayr 1988).
2. The phylogenetic relationships between species that arise through evolution by descent and by transformation of heritable characters, and that should play a major role in the grouping of species (Crisci & Stuessy1980; Crisci 1982; Stuessy & Crisci 1984; Crisci 1985; Hennig 1966; Nelson & Platnick 1981; Wiley 1981; Eldredge & Cracraft 1980).

Thus, one can partition systematics rather clearly into two fields corresponding to the two components of the generative system of living things: microtaxonomy and macrotaxonomy (Hennig 1966; Mayr 1988). Microtaxonomy deals with the delimitation of species and with the description of the population structure of species. Microtaxonomists are concerned with species definition and are especially involved in the study of the geographic variation of species. Macrotaxonomy is the attempt to arrange species in a classification. This means the grouping of closely related species into higher-ranking taxa (such as genus and family) of more distant relationships until the entire Linnaean hierarchy is established.

II. WHAT QUESTIONS DO SYSTEMATISTS ASK?

A. What Is the Current State of Biological Diversity?

The theme of this section, the magnitude of global diversity and the rate at which it is declining, is drawn from an article written by Edward O. Wilson (1988).

Many recent publications, especially the multi-authored volume *Synopsis and Classification of Living Organisms*, indicate that about 1.4 million living species of all kinds of organisms have been described (edited by Parker 1982). This number is consistent with the numerical taxonomic breakdown of the world insect fauna prepared by Arnett (1985). Of the 1.4 million living species, approximately 750,000 are insects, 41,000 are vertebrates, and 250,000 are plants (that is, vascular plants and bryophytes). The remainder consists of a complex array of invertebrates, fungi, algae and microorganisms (see Table 1).

Table 1. Number of described species of living organisms (Wilson 1988).

Kingdom & Major Subdivision	Common Name	No. of Described Species	Totals
*Virus**	Viruses	1,000 (order of magnitude only)	1,000
Monera			
Bacteria	Bacteria	3000	
Myxoplasma	Bacteria	60	
Cyanophycota	Blue-green algae	1700	4,760
Fungi			
Zygomycota	Zygomycete fungi	665	
Ascomycota (including 18,000 lichen fungi)	Cup fungi	28,650	
Basidiomycota	Basidiomycete fungi	16,000	
Oomycota	Water molds	580	
Chytridiomycota	Chytrids	575	
Acrasiomycota	Cellular slime molds	13	
Myxomycota	Plasmodial slime molds	500	46,983
Algae			
Chlorophyta	Green algae	7000	
Phaeophyta	Brown algae	1500	
Rhodophyta	Red algae	4000	
Chrysophyta	Chrysophyte algae	12,500	
Pyrrophyta	Dinoflagellates	1100	
Euglenophyta	Euglenoids	800	26,900
Plantae			
Bryophyta	Mosses, liverworts, hornworts	16,600	

**Some biologists do not classify viruses as living organisms.*

Table 1. Continued

Kingdom & Major Subdivision	Common Name	No. of Described Species	Totals
Plantae (Continued)			
Psilophyta	Psilopsids	9	
Lycopodiophyta	Lycophytes	1275	
Equisetophyta	Horsetails	15	
Filicophyta	Ferns	10,000	
Gymnospermae	Gymnosperms	529	
Dicotyledonae	Dicots	170,000	
Monocotyledonae	Monocots	50,000	248,428
Protozoa			
	Protozoans: Sarcomastigophorans, ciliates and smaller groups	30,800	30,800
Animalia			
Porifera	Sponges	5000	
Cnidaria, Ctenophora	Jellyfish, corals, comb jellies	9000	
Platyhelminthes	Flatworms	12,200	
Nematoda	Nematodes (roundworms)	12,000	
Annelida	Annelids (earthworms and relatives)	12,000	
Mollusca	Mollusks	50,000	
Echinodermata	Echinoderms (starfish & relatives)	6100	
Arthropoda	Arthropods		
Insecta	Insects	751,000	
Other arthropods		123,161	
Minor invertebrate phyla		9300	989,761
Chordata			
Tunicata	Tunicates	1250	
Cephalochordata	Acorn worms	23	
Vertebrata	Vertebrates		
Agnatha	Lampreys and other jawless fishes	63	
Chondrichthyes	Sharks and other cartilaginous fishes	843	
Osteichthyes	Bony fishes	18,150	
Amphibia	Amphibians	4184	
Reptilia	Reptiles	6300	
Aves	Birds	9040	
Mammalia	Mammals	4000	43,853
	TOTAL, all organisms		1,392,485

Most systematists agree that this picture is still very incomplete, except in a few well-studied groups such as the vertebrates and flowering plants. If insects, the most species-rich of all major groups, are included, the absolute number is likely to exceed 5 million. Recent intensive collections made by

Te y L. Erwin and his associates in the canopy of the Peruvian Amazon rain forest have moved the plausible upper limit much higher. Previously unknown insects were so numerous in these samples that when estimates of local diversity were extrapolated to include all rain forests in the world, the resulting figure was 30 million species (Erwin 1983). In an even earlier stage is research on the epiphytic plants, lichens, fungi, roundworms, mites, protozoans, bacteria and other poorly explored areas, including the coral reefs, the floor of the deep sea, and the soil of tropical forests and savannas. Thus, remarkably, we do not know the true limit of species on Earth, even to the nearest order of magnitude (Wilson 1985). The absolute number falls somewhere between 5 and 30 million.

Each species is the repository of an immense amount of genetic information. The number of genes ranges from about 1000 in bacteria and 10,000 in some fungi, to 400,000 or more in many flowering plants and a few animals (Hinegardner 1976). A typical mammal such as the house mouse (*Mus musculus*) has about 100,000 genes. The number of species and the amount of genetic information in a representative organism constitute only part of the biological diversity on Earth. Each species is made up of many organisms. For example, Wilson (1971) estimates that the 10,000 or so ant species comprise 10^{15} living individuals at each moment of time. Except for cases of parthenogenesis and identical twinning, virtually no two members of the same species are genetically identical because of the high levels of genetic polymorphism across many of the gene loci (Selander 1976). At still another level, wide-ranging species consist of multiple breeding populations that display complex patterns of geographic variation and genetic polymorphism. Thus, even if an endangered species is saved from extinction, it probably will have lost much of its internal diversity. When populations are allowed to expand again, they will be more nearly genetically uniform than the ancestral populations. Modern bison herds, for example, are biologically not quite the same—nor so interesting—as those of the early 19th century.

B. What Is the Current Rate of Extinction?

It is difficult to determine precisely the number of species being extinguished because we do not know the number of species originally present. There is no doubt, however, that extinction is proceeding at a rate far greater than that prior to 1800. The basis for this statement is not the direct observation of extinction. To witness the death of the last member of a parrot or orchid species is a near impossibility. With the exception of the showiest birds, mammals or flowering plants, biologists are reluctant to say with finality when a species has finally come to an end. There is always the chance (and hope) that a few more individuals will turn up in some remote forest remnant or other locale. But the vast majority of species is unmonitored. An extreme example is the western forest of Ecuador. The habitat was largely undisturbed until after 1960, when a newly constructed road network led to the swift incursion of settlers and clear-cutting of most of the area. Now, only

patches remain—such as the 0.8-square-kilometer tract at the Rio Palenque Biological Station. This tiny reserve contains 1033 plant species, perhaps one-quarter of which are known only to occur in coastal Ecuador. Many are known at the present time only from a single living individual (Gentry 1982).

The current reduction of diversity may approach that of the great natural catastrophes at the end of the Paleozoic and Mesozoic eras—in other words, the most extreme in the past 65 million years. In at least one important respect, modern extinction exceeds anything in the geological past. In the earliest mass extinctions, which some scientists believe were caused by large meteorite strikes, most of the plants survived even though animal diversity was reduced severely (Raup 1991). Now, for the first time, plant diversity is declining sharply (Knoll 1984).

Table 2. The extent of human genetic variation.

Any two people differ at about 0.1 percent of their DNA bases. Thus, 0.001 (0.1 percent) x 3×10^9 base pairs = 3×10^6 base pairs of variation between any two individuals.

There are approximately 5 billion (5×10^9) people on Earth. Thus, $3 \times 10^6 \times 5 \times 10^9 = 15 \times 10^{15}$ base pairs of potential variation in the human population.

The biological diversity most threatened is also least explored, and there is no prospect at the moment that the scientific task will be completed before a large fraction of the species vanishes. Probably no more than a few thousand professional systematists in the world are competent to deal with the millions of species found on Earth, and systematists themselves are an endangered species because of decreased professional opportunities, reduced funding for research, and the assignment of a higher priority to other disciplines.

The problem of conservation is thus exacerbated by the lack of knowledge and the paucity of ongoing research. Precise assessments and recommendations require knowledge of which species are present (recall that the great majority have not even received a scientific name), their geographical ranges, biological properties and possible vulnerability to environmental change. It would be a great advantage to seek such knowledge for the entire biota of the world. Each species is unique and intrinsically valuable. We cannot expect to answer the important questions of ecology and other branches of evolutionary biology, much less preserve diversity with any efficiency, by studying only a subset of the extant species.

Chapter II

The magnitude and control of biological diversity is not just a central problem of biology; it is one of the key problems of science as a whole. At present, there is no way to know whether there are 5, 10 or 30 million species on Earth. No theory can yet predict what this number might turn out to be. With reference to conservation and practical applications, it also matters why a certain subset of species exists in each region of the Earth and what is happening to each one year by year. Unless an effort is made to understand all of diversity, we fall far short of understanding life in these important respects, and with the accelerating extinction of species, our opportunity to learn about the diversity of life may slip away forever.

C. How Can We Organize Life's Diversity?

What's in a name? For biologists, the answer is everything. For example, the name implies the organism's evolutionary history, its ecological relationships, and even the basic ways the organism "makes a living"—its methods of acquiring and using energy, and its modes of reproduction.

The identification and description of the various species of organisms help scientists think, talk and write about organisms and thus communicate their knowledge to other people. To do this effectively, each species needs a name, and to avoid confusion, each name must be different. An organism's name is the key to our scientific understanding of that organism, from the molecular to the ecosystem level (Ride & Younès 1986). The exchange of information about living and extinct organisms, within and outside biology, depends on the availability of a stable, well-defined and generally recognized set of designations for organisms linked by common descent with a common set of characters. Biological nomenclature, and the rules governing it, are designed to fulfill this need and are generally recognized as basic working tools for biological research and information exchange (Hawksworth & Greuter 1989). Biological nomenclature has two components: (1) a hierarchical system of taxonomic ranks; and (2) a method of naming the taxonomic groups.

1. *Taxonomic ranks.* The formal taxonomic hierarchy is a system of categorical ranks with associated names. The species belong to a series of taxa of consecutively larger and more inclusive, higher ranks. Species are grouped into genera, genera into families, families into orders, orders into classes, classes into phyla, (divisions among plants, animals, fungi and some microorganisms), and finally, the phyla are grouped in kingdoms. There are also intermediate categories, such as subfamily, between genus and family. Such a system, in which there are more and more inclusive categories at higher levels, is called hierarchical. Biological classification, and indeed most classification, is hierarchical. Humans belong to the species *Homo sapiens*, the genus *Homo*, the family *Hominidae*, the order *Primates*, the class *Mammalia*, the phylum *Chordata*, and the Kingdom *Animalia*.

2. *Methods of naming the taxonomic groups.* The simplified system of naming plants, animals and microorganisms that has been standard for more than two centuries stems from the work of the Swedish biologist Carolus Linneaus (1707-1778). This system is called a *binomial nomenclature* because it employs two words to name a species. The scientific or specific name of an organism is a combination of two Latin or Latin-like words. The first word of the species name, which begins with a capital letter, is the name of the genus (the generic name) into which the species is placed; the second word is the specific epithet or descriptive name, indicating the particular species. *Solanum tuberosum* is the scientific name for potato, *Picea rubens* the scientific name for red spruce, and *Dianthus caryophyllous* the scientific name for the common carnation. *Dianthus, Solanum* and *Picea* are the respective generic names, and *tuberosum, rubens* and *caryophyllous L.* are the specific epithets. Species names are usually underlined when written and put in italics when printed.

The genus name and specific epithet together form a binomial called the species name. The term "species name" often is used erroneously to refer to the specific epithet alone, but the species name consists of both the generic name and the specific epithet. The name *Dianthus* can never be used for any other plant, only for carnations. The word *caryophyllous* can never be used for any other species in the genus *Dianthus* although it can be used with the name of some other genus. This would not create duplication because the scientific name must consist of two words.

The principal advantage of the binomial system is that it provides a short, single name for each species. The name is recognized internationally, accepted universally, and tells the reader a great deal about the organism.

The scientific names of the higher taxonomic ranks require standardized grammatical endings. For instance, the names of all families of animals end in **-idae**, and those of families of plants and microorganisms end in **-aceae.**

3. *Codes of nomenclature.* Why use this relatively complicated system of names? Latin names are long and sometimes difficult to pronounce. Why not use common names? The potato (*Solanum tuberosum*) is called "papa" in Spanish and "pomme de terre" in French. These vernacular names are not, therefore, universal. Sweet potato, *Ipomea batata*, is a completely different species from *Solanum tuberosum*. This means that vernacular names are not unique, either. Finally, the ancient Peruvians used the name *batata* to designate *Solanum tuberosum*; this means that vernacular names are not stable.

Uniqueness, universality and stability are important requisites for any system of communication, scientific nomenclature included, and biologists ensure these requisites through a set of rules called *Codes of Nomenclature*. Biologists use four separate codes to deal with the names of all living

organisms: botanical, zoological, bacteriological and viral. The four codes of biological nomenclature have in common four fundamental objectives (Ride 1988):

a. The name of each taxon should be unique and universal in all languages.
b. The scientific names should be stable.
c. The scientific names should be memorable and informative.
d. The rules of nomenclature must not interfere with taxonomy.

The separate development of the codes—particularly the zoological and botanical codes—has resulted in the adoption of different methods to achieve these objectives (McNeill & Greuter 1986; Jeffrey 1986). Six common maxims are used in constructing all codes, however:

a. Each scientific name must be established formally.
b. It must be possible to identify each scientific name unequivocally and to assign it to a taxon without influencing the formation of the taxon.
c. When more than one name is available for a taxon, the choice between them must be unequivocal.
d. There must be no doubt about what is permissible in a scientific name, that is, what may be amended and what must be rejected.
e. Mechanisms must exist to override any regulation that would upset a universal or stable name in use for a taxon.
f. A name should reveal the rank of the taxon and, as far as possible, its affinities.

Other, less fundamental, principles or recommendations are included to promote the dispersal of information, to facilitate interpretation and to promote appropriate etymology. Furthermore, all codes contain provisions that permit administration and updating. The codes have no legal status in national or international law; rather, enforcement depends on the voluntary agreement of systematists. Failure to observe the provisions of the codes, however, can only lead to instability of nomenclature and alter its universality. This would create many problems for those who use scientific names for the range of activities described in Chapter I, Section C.

III. THE GOALS OF EDUCATION IN SYSTEMATICS

The world's natural heritage is being reduced rapidly in both scope and diversity. Perhaps as many as a quarter of all plants, animals and microorganisms will become extinct during the course of our own lives. The expected reduction in the number of species requires that we understand the very nature of biodiversity, and systematics allows us to gather facts about biodiversity and to understand and perhaps maintain this diversity. An understanding of systematics and its role in maintaining diversity is, therefore, an important goal of biological education.

Education about systematics must develop in students an appreciation for systematics as a discipline that addresses the following questions:

a. Why should we study systematics?
b. How many different groups of organisms are there on Earth?
c. How can we organize this diversity so we can better understand it? How do we define, name and identify organisms?
d. How can our system of organization allow us to incorporate new information?
e. How are the organisms on Earth related?
f. What factors result in an increase and/or decrease in diversity and what role do humans play in the process?

Students must be encouraged to value biodiversity and to understand and appreciate the role of biological systematics in preserving this diversity. They must be taught that systematics is more than collecting and naming; it includes methods of investigation and reasoning, a means of communicating information and a complete system of information retrieval.

Equally as important, students must understand that our system of classification is a mutable human construct. Organisms do not come into the world as members of a phylum, genus or species. Humans place them in those categories—and within the context of a larger classification scheme—on the basis of current knowledge and the perspectives of those who designed the classification system to meet their needs. As our knowledge of genetics, evolution, anatomy, development, reproduction, energetics and other disciplines expands, we must reorganize the system of classification, as evident in the expansion of the number of kingdoms from three to five within the last two decades. This is an important lesson for students because it demonstrates the dynamic nature of science and the role of multiple competing hypotheses in scientific progress. This, indeed, should be one of the most important lessons of education in taxonomy.

Toward that end, classrooms must become places where students regularly explore interesting problems using important biological tools. Our premise

is that what a student learns depends to a great degree on *how* he or she has learned it.

A. The Need for a New Approach To Teaching Systematics

There is a clear need for curricular reform in school-based biological systematics. Such reform must address the content of the curriculum as well as approaches to instruction. The present curriculum often fails to foster biological insight, reasoning and problem solving and fails to emphasize interactive activities. Too often in the teaching of systematics, students become passive recipients of meaningless names and information rather than active participants in developing an understanding of major concepts.

An appropriate curriculum for young children that reflects this document's overall goals must involve children in the process of doing systematics. Young children are active individuals who construct, modify and integrate ideas by interacting with nature, materials and other children. Children must be encouraged to explore, describe, name, discuss, investigate, develop, construct and predict.

Active learning has many implications for systematics education. First, teachers must create an environment that encourages children to explore, name, and discuss nature and biodiversity. They need to listen carefully to children and to guide the development of their ideas accordingly. They need to make extensive and thoughtful use of the organisms around the school to foster the learning of such abstract ideas as the diversity of life and the species concept. The teacher also must sharpen children's powers of observation.

Second, the curriculum should emphasize the development of children's classificatory thinking and reasoning abilities. The curriculum must take seriously the goal of instilling in students a sense of confidence in their ability to classify, detect patterns and see classification schemes as hypotheses about nature.

Third, the curriculum should emphasize the application of systematics. If children are to view systematics as a practical, useful subject, they must understand that it can be applied to a wide variety of problems and phenomena that have some meaning for them. Children also need to understand that systematics is an integral part of biology.

B. Curriculum Standards

Standards help to ensure quality curricula, give direction to the attainment of goals, and thereby promote educational changes and understanding of these changes. The Commission for Biological Education (CBE) has identified some standards that we hope will encourage change in the way systematics is taught. Two features are embedded in each of the standards

that is identified. First, knowing systematics is "doing" systematics. Students discover or create knowledge by engaging in activities. Second, the value of information lies in the extent to which it is useful in the course of some purposeful activity.

Sample standards (ages 6-12)

The study of biodiversity at ages 6-12 should include numerous experiences with living organisms of diverse groups so that students can:

- Distinguish living from nonliving.
- Observe similarities and differences between objects and organisms.
- Develop simple classification schemes.
- Relate organisms to other organisms.
- See themselves as part of Earth's biodiversity.
- Realize that biodiversity is a vital part of our everyday life.

Focus

From the earliest grades, the curriculum should give students opportunities to focus on similarities and differences between objects. Children should begin to see that similarities are the essence of classifications. The idea of relationships can be developed intuitively through observation of similarities and differences. Children should use physical materials, pictorial displays and a variety of organisms to recognize and create classifications and relationships. This experience builds readiness for a generalized view of systematics.

A classroom can become a rich environment in which to study classification. A group of students, various furniture, shoes, pencils and selected pictures are examples of materials for classification that children can create. Classification can be as simple as a dichotomous grouping (e.g. classifying students into boys and girls), or more complex, as in the examples provided in the Appendix.

Sample standards (ages 13-18)

The teaching of systematics must avoid overdependence on rote memorization of names. The curriculum should include active problem-solving exercises that focus on one or more of the following suggested standards:

- Systematics as an integrated whole consisting of microtaxonomy, macrotaxonomy and nomenclature
- Ecological relationships
- Human dependence on biodiversity
- The biological species concept
- Phylogenetic systematics
- Nomenclature
- Biogeography

- Computers and systematics
- The fossil record: reconstructing the past.

Although each of the foregoing topics is a valid component of systematics in its own right, the topics should be taught as an integrated whole, not in isolation. The emphasis must shift from one dominated by memorization of names of isolated taxa to one that emphasizes major concepts and a coherent picture of order and diversity.

Teachers should employ a variety of instructional methods in classrooms to cultivate students' abilities to investigate, to construct classifications of organisms, and to make and provide arguments for establishing phylogenetic relationships. These alternative methods of instruction will require that the teacher's role shift from dispensing information to facilitating learning—from that of director to that of catalyst and coach. The introduction of new topics such as nomenclature should be embedded in problem situations posed in an environment that encourages students to explore, formulate and test phylogenetic relationships and discuss the implications of classification schemes as hypotheses about the living world. Such an instructional setting enables students to approach the learning of biological systematics both creatively and independently and thereby strengthen their confidence and skill in doing systematics.

Phylogenetic systematics

Instruction in systematics for ages 13-18 should include the study of phylogeny, phylogenetic reconstruction, and the relationships between phylogeny and classification so that students can:

- Systematically collect, organize and describe data for a study of phylogeny
- Construct hypotheses for phylogenetic relationships
- Apply techniques of phylogenetic systematics
- Develop understanding and appreciation of phylogenetic ideas
- Expand their understanding of evolution.

Almost any group of organisms offers many rich opportunities for exploration in phylogeny. These explorations have payoffs in understanding other concepts in systematics and in illustrating the beauty and importance of biodiversity.

C. Sample Instructional Activities

With the foregoing standards in mind, the Commission (CBE) has identified activities that illustrate the type of experiences students should have in the classroom: activities that involve "doing" systematics, not merely reading about the nature, substance and purpose of this subdiscipline. These activities are reproduced in the Appendix.

There are, of course, barriers to the implementation of new instruction in any area, and this is especially true for systematics, which does not enjoy a favorable reputation among most teachers and students. The best way to bring about reform is to provide instruction that directly challenges the largely negative perceptions that many students and teachers now hold about biological systematics.

We must remember that:

- Biodiversity is a global resource that needs to be preserved.
- The learning of systematics should be an active, constructive process.
- Instruction must be based on real problems that demonstrate the personal and social significance of biodiversity.

If we keep these points in mind, collectively we have a rare opportunity to provide the kind of leadership that will encourage substantive changes in the teaching of biological systematics in schools. These changes will ensure that all students possess both a suitable and a sufficient biological systematics background to be productive citizens in the next century.

Glossary

Classification. The ordering or arrangement of objects into groups or sets on the basis of observable or inferred properties.

Identification. The allocation or assignment of additional unidentified objects to the correct class, once such classes have been established by prior classification.

Macrotaxonomy. The methods and principles by which species are grouped into higher ranking taxa.

Microtaxonomy. The delimitation of species and the description of the population structure of species.

Nomenclature. The application, under some rules, of distinctive names to each of the groups recognized in any biological classification. The purpose of giving a name to a group of organisms is to supply a way to refer to it and indicate its rank. The principal ranks of groups in the system of nomenclature in an ascending series are: species, genus, family, order, class, division (botany) or phylum (zoology). These ranks are called categories. A taxon (plural: taxa) refers to a group of organisms of any rank, for example, *Arum* is a taxon at the rank of genus; Asteraceae at the rank of family; Bryophyta at the rank of division.

Phylogeny. The interrelationships of the members of a group of organisms, as a result of evolution by descent and transformation of heritable characters.

Systematics. The scientific study of the kinds and diversity of organisms and of any and all relationships among them. Systematics, then, is taxonomy plus the biological interrelations.

Taxonomy. The theoretical study of classification, including its basis, principles, procedures and rules. This would include classification, as well as identification and nomenclature. The subjects of classification are organisms, and the subjects of taxonomy are classifications.

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Appendix

Sample Instructional Activities for Ages 6-12

Magnet Mystery

Developed by the Biological Sciences Curriculum Study (BSCS)

Working in teams, students will use a magnet to sort objects into two groups. Then they will record their results.

LESSON OUTCOMES

- Students should be able to sort objects according to properties. They will show their ability by sorting selected objects according to whether a magnet attracts them.
- Students should be able to record their observations. They will show their ability by making a team record of an experiment.

Estimated Time: 2 class sessions

Important note: Group the students into teams of two for this exercise. Each team should have a communicator—one who reports to the class—and a manager—one who organizes and administers the activity. Students should take turns assuming these roles.

MATERIALS

For Each Team of 2 Students:

- One magnet
- One Yes/No handout for each session (see sample on page 38)
- Two resealable plastic bags, quart size, containing:

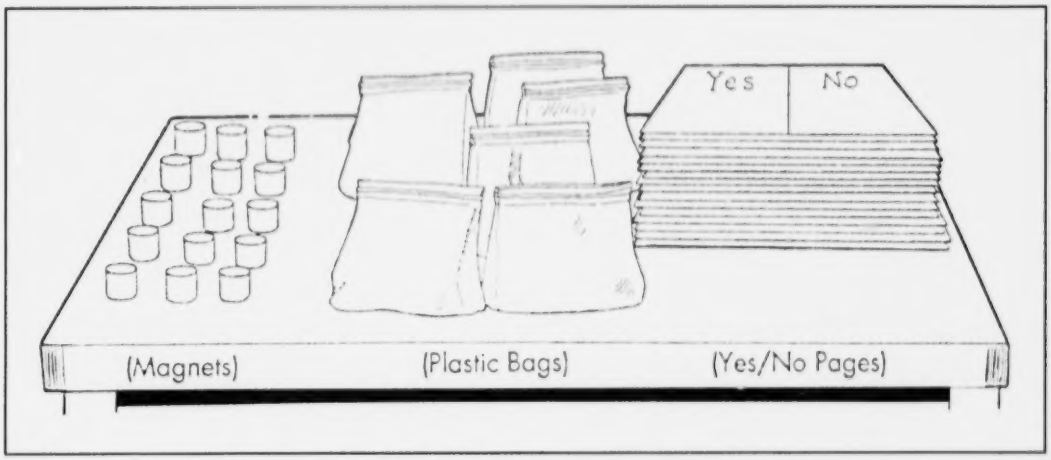
Bag 1 (for 1st class session)	*Bag 2* (for 2nd class session)
Small wad of aluminum foil	Pair of nonpointed scissors
Toothpick	Metal paper clip
Metal jar lid	Plastic straw
Plastic milk lid	Aluminum bottle cap
Aluminum nail	Hex nut
Steel nail	Paper fastener
Twist tie	Penny
	Metal washer

SAFETY CAUTION: Some of these items can be easily swallowed — Exercise caution. For some classes, eliminate small items. Remind students that some objects have sharp points or sharp edges.

BEFORE BEGINNING THE FIRST CLASS SESSION

- Place a set of the objects for Bag 1 into a plastic bag. Prepare a bag for each team and one for yourself. Your students could help you assemble the bags.
- Arrange these filled plastic bags, the magnets and the team Yes/No handouts on the supply table (see illustration on next page).

• Attach a sample copy of a Yes/No handout to the wall where students can see it.



TEACHING STRATEGIES (Session 1)

1. Hold up a plastic bag containing the objects in Bag 1.
   - Tell the students that the bag contains one group of objects.
   - Ask: In how many ways can you sort the objects into two groups?

2. Hold up a magnet. Tell the students that each team will use this sorter to sort the objects in the bag.

(Allow students to discover the special properties of the sorter. Do not tell students that you are holding a magnet. Although students might be familiar with magnets, they might not recognize a ceramic magnet.)

3. Direct students' attention to the supply table.
   - Point out the plastic bags, sorters and Yes/No sheets.
   - Tell managers that they will collect a bag, a sorter and a Yes/No sheet for their teams.
   - Emphasize that partners will share supplies.

4. Explain that the first team task is to find a way to use the sorter to sort the objects in the bag.

5. Direct teams to their workstations, and tell students to begin.
   - Allow teams some time to examine the objects.

(Before using any unfamiliar manipulatives in a task, students will need to examine them briefly. Do not demonstrate how students should use the magnets to sort the objects; they will discover on their own the magnetic

attraction between the ceramic magnet and anything containing iron or steel. Acknowledge this phenomenon to the class, but do not tell students what materials the magnet attracts.)

- Then, tell students to replace the objects in the bag.

(Students will pay more attention to the next set of instructions if they do not have materials in hand.)

6. Encourage students to comment on their observations.
   - Ask: What do you think the sorter is?
   - Call the sorter a magnet as you discuss students' observations.
   - Ask: How could you use the magnet to sort the objects?

7. Explain that the second team task will be to use the magnet to sort the objects in the bag.

8. Give the following directions:

(Emphasize taking turns and sharing materials. Remind students not to put any objects in their mouths.)

- *Step 1*: One partner selects an object and observes whether it sticks to the magnet.
- *Step 2*: Both partners must agree on whether or not the object sticks.
- *Step 3*: The person who selected the object places it on the "Yes" side of the team's Yes/No sheet if the object sticks and on the "No" side if the object does not stick.
- *Step 4*: Partners take turns selecting objects from the bag, testing them with the sorter and placing them on the team's Yes/No sheet.

(Once the partners have emptied the bag, they will have organized the objects into two groups on the page.)

9. Instruct the teams to begin the task.
   - Circulate among the teams.
   - Clarify directions as necessary.
   - Monitor students' use of the team skills, noting how a team practices a skill so you can share examples with the class later.

10. Direct students' attention to the Yes/No sheet that you have displayed.

(Allow students to remain at their workstations for the following discussion. They will need to refer to their teams' Yes/No sheet.)

- Remove one object at a time from your plastic bag.

- Ask: Where on the sample Yes/No sheet should I put each object?

(Encourage students to look at their own page before they respond. Ask different students to tell you where to place each object. If there is disagreement over an object's placement, ask students to test the object again.)

11. Tell students to put all their objects in their bags.

12. Discuss the following points with the class:
    - Before students sorted the objects, all the objects were in the bag.
    - The objects were not organized.
    - Students used a magnet to sort the objects.
    - Students sorted the objects to organize them.
    - Sorting is a way to organize objects.
    - The Yes/No sheet is a record of the way students organized the objects.

13. Inform the class that during the next class session they will use the magnets to organize other objects.

(Remind managers to return the supplies.)

BEFORE BEGINNING THE SECOND CLASS SESSION

Place a set of objects for Bag 2 into a second plastic bag. Again, prepare a bag for each team and one for yourself. Arrange this set of plastic bags, the magnets and team Yes/No handouts on the supply table for use during Session 2 (see illustration on page 33).

TEACHING STRATEGIES (Session 2)

1. Draw students' attention to the objects attached to the posted class Yes/No sheet from Session 1.
    - Remind students how the objects were organized.
    - Tell students that they sorted the objects to organize them.

2. Display your plastic bag of objects (Bag 2) for Session 2.

(Repeating the sorting activity with different objects gives every student an opportunity to perform both manager and communicator jobs.)

- Ask: Are the objects in this bag organized?

(Students should reply that the objects are not organized. Students should

begin to understand when objects are organized and when they are not.)

- Explain that the team task will be to use the magnet to organize the objects in each team's bag into two groups.

(Students should use their Yes/No sheet to organize the objects once they have sorted them.)

3. Announce that students will work in the same teams as in the previous session, but team members will trade jobs.

- If necessary, review the duties of manager and communicator.

(Remind managers to get Bag 2, a magnet and a Yes/No page from the supply table for today's session.)

- Tell teams to go to their workstations and begin the task.

(Circulate among the teams. Make sure students are doing their jobs.)

4. After the teams have sorted the objects, complete the posted class Yes/No sheet.

(Students should again refer to their organization of objects on their team's Yes/No sheet. Quickly add the new objects to the posted Yes/No page, as in the last session.)

5. Tell students that the next team task is to record how they organized the objects in today's bag.

(This task promotes positive interdependence and can easily be conducted as an exercise in cooperative learning.)

- Hand out the "Does It Stick to the Magnet" record form.
- State that partners must share the record form (see page 39).

6. Give the following directions:

- *Step 1:* Look at the Yes/No sheet to decide whether or not an object stuck to the magnet.
- *Step 2:* On the record form, circle "Yes" under the pictures of objects that stuck to the magnet and "No" under the pictures of those that did not stick.

(Partners should take turns making decisions and circling the correct answers.)

- *Step 3:* Put your name on the record form to show that both you and your partner agree on the answers.

7. Direct students to begin the task.
    - When the task is complete, tell managers to replace the objects in the bags, return the bags to the supply table and give the record form to the teacher.
    - Tell students to let their partners know how well they did their jobs.

(It is valuable for students to assess the performance of their teams.)

8. Display each team's record form with the class Yes/No sheet.
    - While the pages are on display, informally encourage students to compare the records.
    - Help the class recognize that even though the class and team records are organized differently, they are both records of how students sorted the objects in the bag.

Sorting Objects

YES	NO
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.
7.	7.
8.	8.

Record Form
(For Session 2)

Does It Stick to the Magnet?

Circle Yes or No.

Yes No

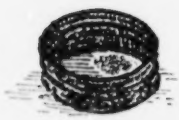
Yes No

Yes No

Yes No

Yes No

Yes No



Yes No

Yes No

Name _____

Name _____

45

Going To Bat for Animals

Developed by the Biological Sciences Curriculum Study (BSCS)

Approximately 99.999 percent of all organisms that have ever lived are now extinct. In fact, it is the fate of all organisms, including humans, to become extinct. Extinction usually results from natural processes. Increasingly, however, humans rather than natural causes create the environmental changes that drive organisms to extinction. In this activity, the students will look at endangered animals, discover some changes that people make, and discuss how they might help reverse changes that harm animals. The activity is appropriate for ages 6-9 and is divided into three 30-minute lessons.

MATERIALS

For Paradise Paved:

- 1200 colored toothpicks, 300 each of red, yellow, green and blue
- Two plastic bags
- String
- Four stakes
- Chalk

For Extinct Is Forever:

For each group of three students:

- One paper plate
- 10 bat counters (see Figure 1)

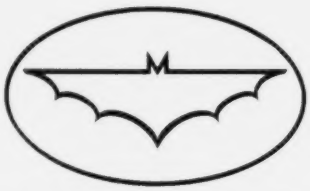


Figure 1. Bat counter.

ADVANCE PREPARATION

1. Locate a grassy area 5 meters square and a paved area the same size for the second day of the activity.
2. Divide the toothpicks into two bags of 600 toothpicks. Be sure each bag contains 150 of each color toothpick.
3. Duplicate enough bat counters (Figure 1) to have 10 counters for every three students. Color each counter red, yellow, blue or green so that you have the same number of each color.
4. Place 10 bat counters on each paper plate. Make sure that each plate holds some red, yellow, blue and green counters.

TEACHING STEPS

Paradise Paved

1. Ask the students to name things that all animals need to live. After the first few answers, categorize responses into five groups on the blackboard. Label these groups food, water, shelter, space and air. Discuss the similarities and differences between the needs of people and other animals. Point out that both people and other animals share the Earth, where they find food, water, shelter, space and air.

2. Ask the students if they could live if they had lots of food, shelter, space and air, but no water. Repeat the question, each time changing the resource that is limited. Emphasize that no matter how much of one resource people have, they must have all five resources to live.

3. Explain that, because humans need resources, they often make changes that endanger other animals. Humans make changes that poison or pollute the food or water that animals need. Sometimes, they make changes that destroy the shelter or space that animals need, and injure or kill animals. Whales, wolves, sea turtles, bald eagles, bats and bears are endangered animals. Animals are endangered when there are very few of them still alive.

4. Take the class outside to a grassy area. With corner stakes and string for the sides, mark off a square with 5-meter sides. Ask the students to stand at the edge of the square. Scatter 600 colored toothpicks on the grass square. Instruct the students to enter the square and collect all the toothpicks that they can find in 30 seconds. After 30 seconds, ask the students to return to their places at the edge of the square.

5. Tell the students to divide the toothpicks into four groups by color. Direct the students to count the number of toothpicks of each color. In which color group do they have the most toothpicks? The students are likely to pick more yellow and red toothpicks than green and blue ones. They will collect the fewest green toothpicks.

6. Tell the students to pretend that the toothpicks were caterpillars that lived in grassy areas and that the students were birds that ate the caterpillars. The caterpillars that were green like the grass were harder for the birds to find. Ask the students if they think that this is an advantage for the green caterpillars.

7. Collect the toothpicks from the students and those still left in the grass. Move to an area that is paved with asphalt or concrete. Using chalk, mark off a square 5 meters on a side and ask the students to stand at the edge of the square. Scatter the second set of 600 colored toothpicks on the paved area. Tell the students that they are birds and instruct them to collect all the caterpillars that they can find in 30 seconds. This time, did the students pick up any one color of toothpick less often than any other? Was the color green an advantage for a caterpillar living on a paved area?

8. Ask the students to consider a change that humans often make to an environment: They pave over wild areas to make parking lots, streets and sidewalks. Would this change endanger green caterpillars? If many more green caterpillars were hunted and eaten by birds because they could be seen easily on the pavement, the caterpillars would decrease in number. They might become rare enough to be an endangered animal. Fortunately, humans can return a paved area to grass; the change to pavement need not be forever.

Extinct Is Forever

1. Divide the students into groups of three. Distribute a plate of bat counters

to each group. Tell the students to pretend that these are all the bats that exist in the world. Ask them to pretend that they are scientists studying bats in different countries, and that each plate represents a different country's bats. Each color of bat represents a different kind of bat (there are different species of bats, just as there are different species of whales or bears). Because each country has some of each kind of bat, the country has a healthy population of bats.

2. Changes are happening in the world that endanger the bat population. Each time a change happens, there are bats that do not survive. If the students lose all of one color of bat, then the bats in that country are endangered. When a country loses all the colors of bats, the country's bats are extinct; the bats are gone forever.

3. Read the following changes one at a time to your students. Tell the students to return to you the bats that did not survive. Have the students check if they have four colors of bats in their country. After each change, ask for a show of hands for countries with healthy bats, endangered bats and extinct bats.

- *Change:* Three bats in each country die because they get a disease.
- *Change:* Two bats in each country die because they ate insects sprayed with chemicals.
- *Change:* Three bats in each country die because caves in which they roost are disturbed.
- *Change:* Two bats in each country are killed because people are afraid of them.

When the bats become extinct, emphasize that the bats are gone forever; there are no more to be seen anywhere in the world. Extinction is a forever change. Put the bats away and do not bring them out again. Ask the students what they might have done to save the bats from becoming extinct.

4. Tell the students that bats really are in danger; several species of bats are already extinct, and others are near extinction. One reason is that (superheroes in bat costumes aside) many people don't like bats. Use information from Background for the Teacher to educate your students about the value of bats. Encourage your students to enjoy bats by reading the children's book, *The Bat Poet*, by Randall Jarrell.

OPTION FOR ACTION

1. Remind the students that there are many endangered animals that need help from people to avoid extinction. Tell your students that there are some things that they can do to help. One is to tell people about endangered animals. To encourage people to ask the students what they know, tell the students to wear "BAT FAN" buttons at school and at home (Figure 2). The

students will explain to anyone who asks about the button that bats, like many animals, are endangered and need people to help them survive.

2. Help your students plan a way to raise money to build bat houses or adopt an animal. Write to the following organizations for specific information about adoption procedures or projects they sponsor:

- Bat Conservation International, P.O. Box 16203, Austin, TX 78716
- HEART (Help Endangered Animals - Ridley Turtles), Box 6811231, Houston, TX 77286-1231
- The International Crane Foundation, E-11376 Shady Lane Rd., Baraboo, WI 53913-9778
- Friends of the Sea Otter, Box 221220, Carmel, CA 93922
- Save the Manatee Club, 1101 Audubon Way, Maitland, FL 32751
- International Wildlife Coalition, Whale Adoption Project, 634 N. Falmouth Highway, P.O. Box 388, N. Falmouth, MA 02556
- World Wildlife/Conservation Foundation, P.O. Box 4866, Hampden Station, Baltimore, MD 21211
- Peregrine Partnership, 1560 Broadway, Denver, CO 80202
- Save the Whales Campaign, Animal Welfare Institute, P.O. Box 3650, Washington, D.C. 20007
- Wolf Action Network, P.O. Cox 6733, Bozeman, MT 59771.

Note: We realize that the above organizations are all located in the USA, but comparable organizations are found in other countries of the world.

BACKGROUND FOR THE TEACHER

Bat folklore goes back many centuries. Aesop, in several fables, depicted bats as unscrupulous liars. The Mayans of Central America drew bats as gods of darkness and the underworld. John Heywood, an English poet, wrote that "These creatures that fly like birds, bite like beasts, hide by day, and see in the dark can surely be neither flesh, nor fowl, nor good red herring."

Bats are the only mammals that can fly. Bat wings are thin membranes of skin that stretch from a bat's body to the elongated bones of its forearm, hand and fingers. Bat faces look peculiar because of their enlarged ears and structures on or around their noses. Bats are not blind, but they use many of these facial structures in echolocation. A bat emits ultrasonic sounds through its mouth or nose. These sounds echo from nearby objects and are picked up by its ears. This method of orientation allows bats to avoid striking objects in their path and to locate, identify and capture tiny moving prey in total darkness.

Most bats eat moths and beetles, although they also consume mosquitos, flies, grasshoppers, cockroaches, termites, flying ants and other insects. Insect-eating bats control the size of insect populations; bats consume a third

of their body weight in insects each night. Only three of the 900 species of bats feed on blood. These vampire bats are capable of spreading rabies whenever they feed but, like other mammals, they either become paralyzed and die when they are infected with rabies, or they survive exposure without spreading the disease. The vampire bats inhabit Mexico, Argentina and Chile, and rarely consume human blood.

Figure 2. "BAT FAN" button.

Bats are important commercially as pollinators and seed dispersers. Flower-visiting bats live in tropical and near-tropical regions. These bats travel from blossom to blossom, transporting pollen. For many plants, such as saguaro cactus, balsa trees and some agaves, bats are the primary agents of pollination.

Bats spend the majority of their lives roosting. They roost in caves and such structures as mines, cellars and tunnels. Roosts provide bats with protection from predators and unfavorable weather. While under this protection, bats can rest, sleep, hibernate, eat, digest, hunt, groom, communicate, mate, give birth and raise young.

The population of bats has experienced a major decline during recent decades. Several species of bats already are extinct, and others are near extinction. People are the major threat to the survival of bats. When people use agricultural pesticides to kill insect pests, the pesticides can poison the insect-eating bats. If people arouse bats during hibernation, the bats lose valuable stored fat and can starve to death before their food supply emerges in the spring. When people destroy habitat for crops, livestock and housing, bats—as well as many other animals—suffer.

Concern about the worldwide decline of bats has led to conservation efforts. Special gates in front of cave entrances allow easy passage for bats but exclude people. Bat houses and towers placed in forests and backyards attract insect-eating bats. People are restoring bat roosts that have been disturbed. Many countries offer bats legal protection; in the United States a number of species are protected under the Endangered Species Act. Through education, people are changing their negative attitude toward bats and are realizing the ecological, economic and scientific value of bats.

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RESOURCES FOR THE TEACHER

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Sample Instructional Activities for Ages 13-18

The "Musical" Method of Teaching Classification

Developed by
Kathryn V. Lykins

It is often difficult for teachers to engage student interest in the topic of biological classification; yet it is an important topic. Those of us who teach biology want our students to understand that classification is a means of grouping organisms by shared characteristics, that classification involves a hierarchical structuring of the living world, and that classification serves distinct purposes.

In discussing the nature and purpose of biological classification, biology texts typically introduce the topic by referring to the grouping of similar items in grocery stores or related books in libraries. Although all young people are interested in food and many are interested in books, I've always found these analogies to be lacking in interest and excitement. How can teachers present biological classification in a manner that will engage student interest?

An activity that has always worked well for me is to introduce students to biological classification by having them classify music. I have found that a discussion of musical classification will have all students on task and will help them see the need for biological classification and even appreciate why phyla need to be further divided into classes, classes into orders, and so on.

GETTING STARTED

At the start of the class, quietly go to three students and ask them to tell you the name of their favorite singer or group. (If feasible in your particular teaching situation, you could obtain this information before class begins.) Choose these three students with care since your objective here is to have the names of three singers or groups representative of three very different types of music. By the time you are ready to teach classification, you probably have observed your students' clothing styles and social groupings well enough to predict their musical tastes. My aim is always to choose one country fan, one rap fan and one rock fan. If you choose two students who name artists in the same category, ask other students until you have three artists representing the categories. If a name given is unfamiliar to you, ask the student what type of music that person or group performs.

Once you have the three names, write them across the top of the chalk board, e.g.:

Def Leppard Public Enemy Travis Tritt

Alphabetize the names to avoid charges of favoritism. Don't write anything other than the three names. Once you have the names on the chalkboard, ask the class, "What should I write next?" Warning: Be prepared to use your best classroom management skills here; students who have previously displayed little or no interest in your class will be calling out answers. Manage the activity so that everyone has a chance to participate.

FOLLOWING THROUGH

Your goal is to complete a rap column, a rock column and a country column. You don't have to be particularly knowledgeable about popular music because your students will tell you "what goes where." After you have a few names in each column, ask the students, "What are we doing here?" Accept their answers about grouping and mention that this is how you have chosen to introduce biological classification. Then let the students continue suggesting names until the chalkboard is filled.

Subgroupings will probably come up as a natural part of the activity, but if they don't, you can introduce them. Often someone will mention a "quiet storm" artist, such as Whitney Houston. ("Quiet storm" refers to romantic ballads which might generally be considered to be a type of rhythm and blues.) When asked which of the three columns this name should be placed in, students will often indicate the "rap" column, arguing that rap and quiet storm belong together because they are both "black" music. Ask the students if Motown, soul, rap and quiet storm should all be grouped together as black music. Point out to the students that perfectly legitimate arguments can be made for that approach and equally legitimate arguments made for using the subgroupings of rap, Motown, quiet storm and soul since these are four distinct types of music, although all were originated by black artists.

The discussion of musical subgrouping is an excellent way to help students understand why there are differences of opinion among biologists about classification systems. I always explain that we will be using the five-kingdom system, but that the two-kingdom and three-kingdom systems have valid arguments in their favor as well. Students can readily appreciate the comparison between differences of opinion regarding musical classification and differences of opinion regarding biological classification. They can also see the necessity of choosing a classification system and using it consistently.

Once you have discussed the different systems of kingdoms now in use in biology, concentrate on the need for subdividing the three major musical groupings you have listed. Generally the students will make you aware of this, perhaps with the subgrouping of black music as described above, perhaps with an insistence on dividing the rock category. Typically, students will tell you that certain names (R.E.M. and Metallica, for instance) don't "belong together." This presents the perfect opportunity to make an analogy between the original three major groups (country, rap and rock) and the kingdoms used in biology. Explain that just as it can be helpful to subdivide the rock category into smaller groups, such as classic rock, alternative rock, heavy metal, punk rock, soft rock, etc., biologists subdivide kingdoms into phyla.

BRINGING IN THE BIOLOGY

Since students are generally interested in animals, I ask them to picture an animal in their mind. "Most of you have probably thought of some type of furry animal—a mammal," I say. My next question is, "What other types of animals are there?" The ensuing discussion leads them through the division of animal phyla into vertebrates and invertebrates, and the division of both vertebrate and invertebrate phyla into classes. You'll want to keep this simple, of course. Discuss mammals, birds, reptiles, amphibians and fishes, but don't get into Agnatha, Chondrichthyes and Osteichthyes in this lesson. In discussing invertebrates, I emphasize insects and mention that, of course, they know there are many different types of insects, so that class is divided into many orders.

Using the "musical" method also gives you the opportunity to emphasize the usefulness of classification. Ask your students to imagine two record stores, each as big as the biggest mall they've ever seen. Tell them that in the Big Unclassified Mall, all CDs, tapes and records would be arranged alphabetically. The "B" section would have the B-52s, the Beastie Boys, Garth Brooks, the Beatles, J.S. Bach (and all his sons), George Benson, the Black Crowes, etc. The Great Classified Mall would have CDs, tapes and records arranged alphabetically too, but they would first be divided into sections as, in fact, they are in most music stores. Customers at the Great Classified Mall would find country, rap, rock, blues, bluegrass, rhythm and blues, gospel, contemporary Christian, jazz and classical sections. Students will generally agree that they would prefer to shop at the Great Classified Mall.

OTHER LESSONS TO BE LEARNED

An added benefit to this exercise is that you will learn a lot about your students, and much of it may surprise you. Although I can usually guess which type of music a particular student would prefer, I have had some startling surprises. And always there are students who ask me why I am "leaving out" jazz and/or classical music.

In doing this exercise, you also have the opportunity to let your students learn a little bit about you. Be honest! Of course, a teacher's musical tastes are never part of the biology curriculum, but in discussing music, you have a chance to validate all your students' musical tastes and point out that the world would be a very dull place if we all liked the same things. You can encourage students to be open to new experiences. I like to remind students that people change, and that because we change, we need to re-evaluate our thinking from time to time. Often we make decisions about music, about food, and about academics at an early age and get trapped in those early patterns of "not liking" classical music, broccoli or science. As a teacher, you have no doubt often heard students say, "I don't like science," and you know that a large part of teaching science successfully is to get the students to like science at least a little better. To do that, you have to capture the

students' attention, and generally speaking you have to get the students to see you as a person to whom they can relate. These objectives, along with the objectives directly related to biological classification, can be achieved through the "musical" method of teaching classification.

Author's Note:
I developed this approach to the teaching of classification during the second of my six years of public school teaching. At the high school level, this is an appropriate introduction to a lecture on classification. At the college level, this activity is most appropriate when used at the beginning of a laboratory period in which students will be working with classification, such as the construction and/or use of a dichotomous key.

Editor's Note:
The examples used to illustrate this classification exercise are familiar to American students; however, teachers are encouraged to modify this activity using music that is indigenous to their region.

The Nuts & Bolts of Classification

Developed by
Douglas J. Glasenapp

The nuts and bolts exercise is an inexpensive and effective way of explaining the use, construction and value of a dichotomous key. It readily reinforces the concept of classification dealing with similarities and differences. Not strictly for upper class students, this exercise can be used for any level student. I have used it successfully at the high school and junior high school levels. The exercise is completed usually in two class periods of 45 minutes each. After the students have completed the lab, I have found it an excellent vehicle for group discussions. This one excercise has opened the door to many other important topics. As a direct result of this exercise, we have discussed such diverse topics as families of organisms, types of animals, similarities in fruits and animals, hunting rights and fishing rights.

LESSON OBJECTIVES

The objectives of the exercise are:

1. To learn how to design a dichotomous key.
2. To construct a dichotomous key.
3. To use the dichotomous key the student has designed.

MATERIALS

The equipment is inexpensive, but it does take a little time to collect. The best place to go is the local hardware store. (Please see Figure 1 for the items that I use.) I would suggest purchasing 20 of each item; then there will be 20 sets in the end. I usually have my students work in groups of two. My normal

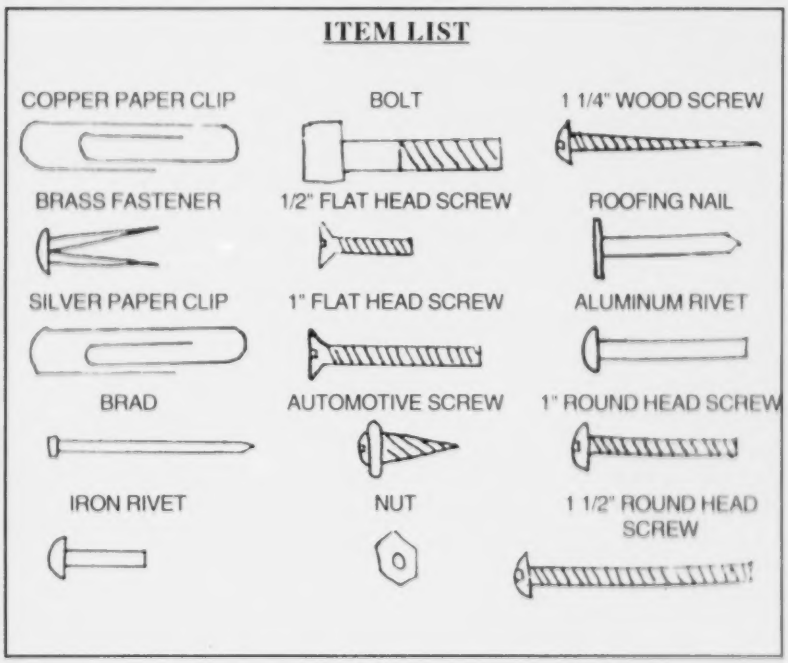

Figure 1. Items for Nuts & Bolts exercise.

class size is 32, so this allows for a reserve of four sets. I keep each set in a numbered baby food jar. Instructors may choose items other than those I have selected, but certain structures such as head type, threads, size, color and shape should be kept in mind.

I have found an easy and effective way to keep items from being lost. I assign a lab monitor in each class. The students check a jar out at the start, making sure everything is there, and check it in at the end. The student monitor counts the items in each jar to insure none is missing. If an item is missing, the students usually find it right away. It does not take that much time and it works! Try it! Normal cleanup time is four to five minutes.

PROCEDURES

Before starting the lab exercise, the instructor should discuss Linnaeus, scientific names and dichotomous classification of trees, fish, insects and other organisms. There are many good reference books with dichotomous keys to use as examples. One possible introduction would be to question the students to find out if anyone knows how to construct a dichotomous key. Then proceed to prepare the students to do this exercise, which will help them understand the methods of construction and use of a dichotomous key.

The procedures are rather simple. Each pair of students picks up a jar full of nuts and bolts, checking to make sure the collection is complete. I instruct the students to make a chart of all the items and to draw them in their lab report at the start of the exercise. It is helpful first to familiarize the students with the items. The students construct a dichotomous key in any order, as long as it works. Be sure to tell them not to use the proper names in the explanation of an item; proper names will be used when it is finally keyed out. The students should try to use characteristics they can readily see. Such things as color, shape, threads, grooves, points, heads, etc. work well. I would not accept "big," "little," "long" or "short" as an explanation. However, exact measurements are acceptable, so I suggest you keep a supply of rulers for this purpose. (Please see Figure 2 for a completed example.)

DATA

The data the students collect would be a working dichotomous key for the items in the jar. I check each key to make sure it works; if it does not work, the students have to redesign it starting from the point of the problem. Once a group is finished, I allow them to try other students' keys and compare. I found the student-to-student contact and comparison works very well. This interaction is similar to team work, where one student can help another group with a minor problem.

CONCLUSIONS & FOLLOW-UP

All students are required to write a summary conclusion of what happened

1. Copper in color.....copper paper clip
   Not copper in color.....2
2. Brass in color.....brass fastener
   Not brass in color.....3
3. Has a shaft.....5
   Does not have a shaft.....4
4. Six sided.....nut
   Does not have six sides.....silver paper clip
5. Pointed shaft.....6
   Does not have a pointed shaft.....9
6. Has threads.....7
   Does not have threads.....8
7. Two piece head.....automotive screw
   Does not have a two piece head.....1 1/4" wood screw
8. 1/2" wide head.....roofing nail
   Does not have a 1/2" wide head.....brad
9. Has a groove in the head.....10
   Does not have a groove in the head.....12
10. Has a threaded shaft.....bolt
    Does not have a threaded shaft.....11
11. Black in color.....iron rivet
    Not black in color.....aluminum rivet
12. Has a round head.....13
    Does not have a round head.....14
13. Shaft is 1" long.....1 1/2" round head screw
    Shaft is not 1" long.....1 1/2" round head screw
14. Shaft is 1/2" long.....1/2" flat head screw
    Shaft is not 1/2" long.....1" flat head screw

Figure 2. A sample dichotomous key.

and what they gained from doing this exercise. Some students learn much more than others, so a group discussion is an effective follow-up exercise. It is now easier for the students to understand the workings and design of the fish key or tree key that may have been difficult when they first saw it.

We come back to the Nuts and Bolts Exercise many times during the school year. Each time we start a new phylum in the animal or plant kingdom, we review how a key works, making it easier for the student to visualize the similarities and differences among the organisms.

With this much experience, the students should be able to use dichotomous keys with facility. We start the chapter on the fish with a lab exercise on Fish Identification, and in our discussion of Wisconsin Trees we use a dichotomous key to select a Christmas tree. These are but a few of the many ways an instructor can incorporate keys into the biology classroom.

FINAL THOUGHTS

The instructor could substitute any number of things for the nuts and bolts: sewing items, nails, shells, make-believe creatures, colored shapes, books, writing utensils, pots and pans, or whatever the instructor feels comfortable with. The ideas are limitless, and this allows the students to have a "hands-on" experience with classification and dichotomous keys. I hope science instructors find keys and working with them more enjoyable after trying this Nuts and Bolts lab experience.

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Dichotomous Keys

Developed by
Kathryn Green

Dichotomous keys are tools used by biologists to identify biological organisms. They may, however, be written to identify any group of objects in which no two individuals are exactly the same. Having students write keys helps them with observation skills as well as recording and organizing data. This activity was designed to be done at or near the beginning of a new term. Characteristics that could be considered too personal—weight, family income, etc.—cannot be used in the dichotomous key.

LESSON OBJECTIVES

1. Students will construct a dichotomous key and be able to make inferences from it.
2. Students will quickly become acquainted with each other, easing cooperative learning strategies.

PROCEDURES FOR THE TEACHER

1. Find or create a simple dichotomous key for students to use as an example.

2. After students have gathered their data, lead them through a discussion of how to work with it by the process of elimination. Try an example that uses shoes: Have 10 students each donate a shoe and have the class write a key for the shoes on the board.

PROCEDURES FOR THE STUDENT

1. List the characteristics you will be observing and recording for each student.

2. Construct a data sheet using these characteristics and record appropriate data next to each student's or teacher's name (see Figure 1).

3. Write a dichotomous key that will identify any 20 students in your biology class, as well as your teacher (see Figure 2).

The following rules must be observed:

- You may not have any more than two choices at any one step of the key.
- Start with general choices and move to more specific ones.
- For each choice, you must either be sent on to another part of the key or end at the name of a person in your class.
- Each student's key may be different, and each must work.
- Use a chart to record the names of the 20 students you will classify and the characteristics used for the classification. Don't forget to include your teacher in the key.

HELPFUL HINTS

If you instruct the students to include you as one of their 20 people, it makes it very easy to grade—just see if you key out properly.

Figure 1. Sample Data Sheet for development of a dichotomous key done by a 10th grade student.

	CHARACTERISTIC										
Names	Hair Length	Hair Color	Eye Color	Sex	Height	Shoe Size	Braces	Glasses	Age	Fav. Color	Fav. Class
Jane	Shoulder	Brn/Red	Blue	F	5'3	7 1/2	No	No	15	Blk	Span.
Juan	Short	Blk	Brn	M	5'4	9 1/2	No	No	15	Grn	Math
Dillon	Short	Blonde	Blue	M	5'10	11	No	No	15	Blue	Math
Ramona	Med.	Lt. Brn	Blue	F	5'2	9	No	No	15 1/2	Grn	C.G.
Vicky	Long	Blk	Grn	F	5'4	6 1/2	No	No	16	Blk	Span.
Art	Short	Brn	Blue	M	5'7	10 1/2	No	No	15	Blk	Lunch
Marty	Short	Dk. Brn	Grn-Bl	M	6'	9 1/2	No	No	15	Purple	P.E.
Sonya	Med.	Brn	Hazel	F	5'7	8	No	No	16	Blk	None
Mandy	Short	Blk	Brn	F	5'1	7	No	No	15	Grn	Lang.
Linda	Shoulder	Brn	Brn	F	5'8	9	No	No	15	Grn	Span.
Karla	Long	Blonde	Grn	F	5'	6	No	No	16	Red	History
Mary	Short	Brn	Brn	F	5'5	8 1/2	No	No	15	Grn	Math
Marisa	Long	Brn	Brn	F	5'6	7	No	Yes	15	Blk	Study
Ally	Long	Blonde	Blue	F	5'5	9	No	Yes	15	Grn	Typing
Teacher	Short	Brn	Blue	F	5'4	5 1/2	No	Yes	old	Blue	Biol.
Becka	Shoulder	Blonde	Brn	F	5'2	5	No	No	15	Grn	Lunch
Hannah	Long	Brn	Blue	F	5'8	9	No	No	15	Blue	Actng.
Amy	Med.	Blonde	Blue	F	5'7	9	No	No	15	Purple	Psych.
Bonnie	Med.	Brn	Brn	F	5'1	9 1/2	No	No	15	Purple	Lunch
Kathy	Long	Red	Brn	F	5'4	8	No	No	16	Green	None

Figure 2. Example of a dichotomous key done by a 10th grade student from data in Figure 1.

1A.	Male	2
1B.	Female	5
2A.	Blue eyes	3
2B.	Eyes not blue	4
3A.	Brown hair	Art
3B.	Blonde	Dillon
4A.	Favorite class math	Juan
4B.	Favorite class P.E.	Marty
5A.	Age 15	6
5B.	Age not 15	16
6A.	Eyes blue	7
6B.	Eyes brown	11
7A.	Wears glasses	Ally
7B.	Does not wear glasses	8
8A.	Shoe size 7.5	Jane
8B.	Shoe size 9	9
9A.	Hair color brown	10
9B.	Hair color blonde	Amy
10A.	5'2" tall	Ramona
10B.	5'8" tall	Hannah
11A.	Short hair	12
11B.	Hair not short	13
12A.	5'1" tall	Mandy
12B.	5'5" tall	Mary
13A.	Wears glasses	Marisa
13B.	Does not wear glasses	14
14A.	Favorite class Spanish	Linda
14B.	Favorite class Lunch	15
15A.	Hair color blonde	Becka
15B.	Hair color brown	Bonnie
16A.	Eye color green	17
16B.	Eye color not green	18
17A.	Hair color black	Vicky
17B.	Hair color blonde	Karla
18A.	Eye color blue	Teacher
18B.	Eye color not blue	19
19A.	5'7" tall	Sonya
19B.	5'4" tall	Kathy

Constructing Dichotomous Keys

Developed by
Sharon Zupo

This lab introduces the concept of dichotomous keys and their construction. Basic skills of defining, organizing and classifying simple classroom items by their common characteristics will be accomplished by students. Rather than obtaining specimens outdoors, this introductory lab is a great time saver because materials are used that are easily accessible in the science classroom.

LESSON OBJECTIVES

1. The student will understand the purpose of a dichotomous key.

2. The student will demonstrate the use of observations instead of inferences.

3. The student will demonstrate the use of quantitative observations over relative terms whenever possible.

4. The student will demonstrate knowledge of the use of a dichotomous key by keying out an assigned specimen.

MATERIALS (per group of 2–3 students)

- Glass beaker (or baby food jar)
- Piece of chalk
- Rubber band
- Dissecting needle
- Metal tweezers
- Metal pin
- Glass rod
- Scissors
- Cork
- Nail

(Place all items in a beaker for ease of handling. Also, write the names of the objects on the chalk board.)

PROCEDURE FOR THE TEACHER

To demonstrate the making of a dichotomous key on the board, the teacher should have the students assist in constructing a key of the students in the class. Begin by asking for common characteristics which will separate the students into approximately two equal groups. Usually male vs. female becomes the first suggested choice, followed by tall vs. short or dark vs. light hair—characteristics that can be observed by all members of the class. These characteristics can be used to reinforce the difference between observation and inference and the use of quantitative observations instead of relative terms (see Helpful Hints). Completion of five to seven steps in the key on the board is sufficient to demonstrate the process. Avoid characteristics such as color of eyes, the wearing of orthodontia, etc., which are difficult for everyone to observe.

Constructing Dichotomous Keys

PROCEDURE FOR THE STUDENT

Obtain a beaker with the nine objects to every two students. The teacher will have written the 10 object names (including the beaker) on the board. Working together, the students should create a dichotomous key of the 10 objects using common characteristics that are observable. For instance, when describing the dissecting needle, you should write "10 cm long," not "... is used for dissections." When students have completed the task, the teacher will follow their key to physically move the objects into subsequently smaller groups as per their instructions to visually demonstrate the model they created. Then have the students make a new dichotomous key of the same 10 objects using all new criteria. This will be a good challenge!

HELPFUL HINTS

Remind the students to use quantitative observations whenever possible. Avoid inferences and relative terms. (Instead of tall vs. short, use 5'6" and over vs. under 5'6"). Avoid traits that might fit into two groups. The dissecting needle contains both wood and metal, so groupings should not contain a choice of "contains wood" vs. "contains metal." This would also create the problem of which category would include the chalk or the rubber band. An example of the dichotomous key format is:

- 1A Made up entirely of metal ... go to step 2
- B Doesn't contain metal ... go to step 5
- 2A 5" long and over ... tweezers
- B Under 5" long ... go to step 3
- 3A
- B

The examples following these instructions can be used as additional exercises or tests.

SUMMING UP

Students enjoy the hands-on experience of making the dichotomous keys. Physically moving the objects with common characteristics into progressively smaller groups visually demonstrates the concept of the key. Students soon realize there is no one correct method to construct a key.

To extend this exercise, books that include keys to mushrooms, flowering plants, birds, insects, trees, etc., can be set out in the classroom to demonstrate the practical use of what the students have just completed. Specimens of leaves, twigs, insects, flowers, etc. should be assigned for students to key-out.

The following types of flies were found in the darkest jungles of Africa. Below are the characteristics of each:

TYPE A — 2 pair antenna, lanceolate wings, black eyes, striped body

" B — 1 pair antenna, no wings, white eyes, striped body

" C — 2 pair antenna, lanceolate scalloped swings, black eyes, striped body

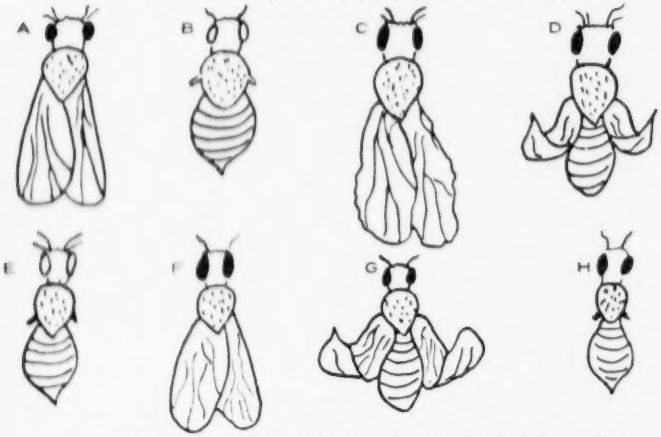
" D — 2 pair antenna, curly wings, black eyes, striped body

" E — 2 pair antenna, no wings, white eyes, striped body

" F — 1 pair antenna, lanceolate wings, black eyes, striped body

" G — 1 pair antenna, curly wings, black eyes, striped body

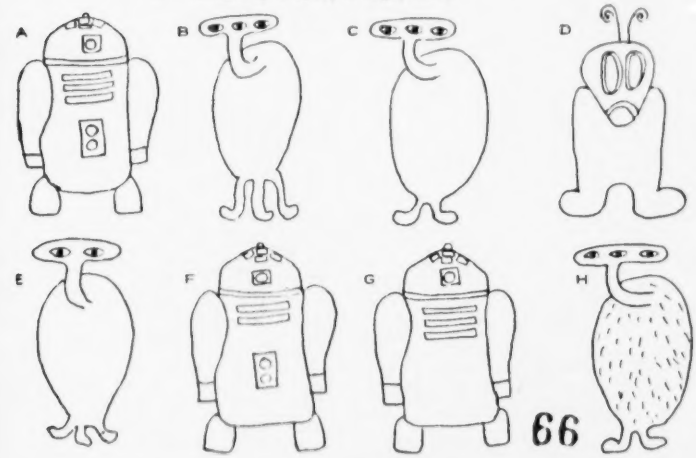
" H — 1 pair antenna, no wings, black eyes, striped body



MAKE A KEY AND CLASSIFY THESE TYPES OF FLIES

Luke, Obi-Wan Kenobi and their sidekicks R2-D2 and C-3PO in their mission to save the Princess Leia from the evil Galactic Empire commanded by Darth Vader, travel to a space-port bar where they encountered the following creatures--as yet unnamed. Make a dichotomous key below using only the information given. Good luck and may the force be with you!!!

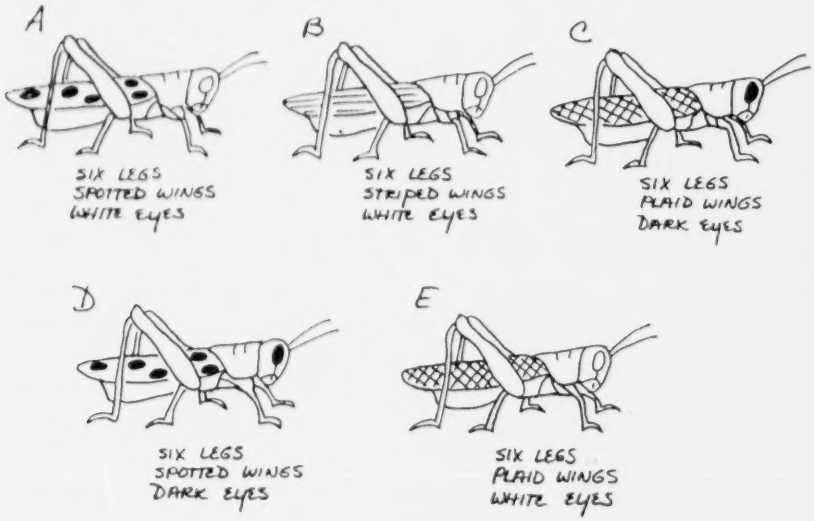
A - metallic, 3 memory banks, radio receiver and transmitter
B - humanoid, 3 eyes, 3 legs
C - humanoid, 3 eyes, 2 legs
D - humanoid, 2 eyes, 1 pair antenna
E - humanoid, 2 eyes, 3 legs
F - metallic, 2 memory banks, radio receiver and transmitter
G - metallic, 3 memory banks, no radio receiver and transmitter
H - humanoid, 3 eyes, 2 legs, hairy



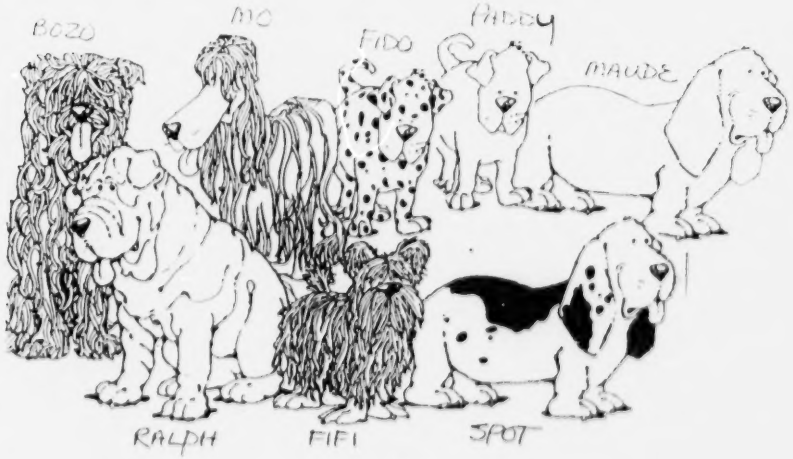
66

Handout #2

The following grasshoppers were captured by a student on a field trip. He made drawings and observations on each. Make a dichotomous key using only the observations listed.



Make a dichotomous key of the 8 dogs found in the picture. You may choose your own characteristics.



67

Classifying Plants & Animals in a Public School

Developed by
Dr. S. Frejlak

The use of keys and atlases for identifying plants and animals is a requirement for students in Poland. To meet this requirement, students need to:
1. Learn about the taxonomic units in their hierarchical order.
2. Understand the basic principles of classification.
3. Understand the objectives and tasks of biological taxonomy.

The lack of suitable keys for identifying plants and animals is a major problem in teaching classification of organisms. Widely available publications are not suitable for secondary school students. There is, therefore, a need for special keys and atlases containing a limited number of common species without morphologic-anatomic details and without abbreviations and terms making it difficult to understand. Because there is a limited number of school hours for the completion of the unit "Principles of the Classification of Plants and Animals," the lessons must be well-organized and must make use of additional activities such as excursions to explore nature, working in a school garden, and competitions concerning botanical knowledge.

LESSON 1 OBJECTIVES

Subject: Principles of the classification of organisms

1. Content Knowledge

- Making the students aware of the great number and variety of plants and animals living on the Earth
- Understanding the need to organize (classify) the organisms according to established criteria
- Learning the principles of an artificial and natural system of classification of organisms
- Learning the basic items of biological taxonomy
- Understanding the principle of double terminology (binomial nomenclature) used in biology.

2. Skills

- Defining objectives and tasks of biological taxonomy and giving the reasons for the need to classify organisms
- Explaining the need for classification of organisms in connection with research and tasks of economy
- Using basic units of biological taxonomy
- Using examples to explain the principle of double terminology (binomial nomenclature) of plants and animals.

MATERIALS

- A school book
- Glass cases with lichens, mosses, a set of mollusk shells and other specimens
- Keys for identifying plants or animals
- Tables and colored chalk or a print projector with a screen and a set of colored pencils.

Classifying Plants & Animals in a Public School

Questions for discussion include:
- What defines the unity and diversity of plant and animal tissues?
- Can we illustrate the notion of unity and diversity with examples from the world of plants and animals?

The teacher informs the students that they will learn and discuss the principles of classifying various plants and animals. Students are told to look at the specimens of lichens, mosses and mollusk shells gathered on the table and describe ways they are identical or similar. They are to write down their remarks and compare them with the remarks of the others in their group.

The students should answer the following questions based on background readings provided by the teacher:
- Is there a need to organize (classify) organisms? If so, why?
- What name do biologists give to the branch of biology dealing with the classification of organisms?
- What are the objectives and primary tasks of biological taxonomy?

The students then construct a summary table (see Table 1 below).

Table 1. Taxonomic Units (names & examples)

Taxonomic units used in botany		*Taxonomic units used in zoology*	
Name	Example	Name	Example
Kingdom	Plantae	Kingdom	Animalia
Division*	Angiospermophista	Phylum	Chordata
Class	Dicotyldoneae	Class	Mammalia
Order	Rosales	Order	Rodentia
Family	Rosaceae	Family	Muridae
Genus	*Rosa*	Genus	*Mus*
Species	*Rosa canina* (rose)	Species	*Mus musculus* (house mouse)

*Botanists use the term "division" instead of "phylum."

The teacher informs the students that the species is the basic unit of taxonomy and discusses with them the definition of a species.

The students, with the help of the teacher and partially on the basis of the background readings, write the examples in the table of taxonomic units. Identical or different names of taxonomic units used in botany and zoology are marked with colored chalk or pencils. The result of this didactic action is an understanding of the principles of classifying organisms and explaining

that apart from basic units, additional units such as subtype, subphylum and subfamily are used. This explanation is only informative, and the students are not obliged to remember particular additional units of biological taxonomy.

Next, an explanation of the principle of double terminology (binomial nomenclature) of plants and animals should follow (see Table 2 below).

Table 2. Popular & Scientific Names (examples)

Popular Name	Scientific Name
Rose	*Rosa canina*
Coalmouse	*Parus major*
Human	*Homo sapiens*

Items that should be addressed by students include:
- What does taxonomy of plants and animals deal with?
- Show the differences between the artificial and natural system of the classification of plants and animals.
- Define the notion of species.
- List taxonomic units—from the most inclusive to the least inclusive—used in botany and zoology.

Formulating other questions is advisable, for example:
- Give examples of binomial nomenclature.
- Who is the author of the principle of binomial nomenclature for plants and animals used in botany and zoology?

The teacher can suggest the following subject for homework: "Discuss the reasons for the use of the system of classification for plants and animals."

LESSON 2

Subject: Principles of the classification of organisms
A second lesson is added to insure students can use keys and atlases to identify plants and animals.

MATERIALS

- Didactic keys
- Specimens of flora and fauna that can be found in didactic keys
- Proper keys for identifying plants
- Specimens for identification (e.g. pansy, gladiolus and tomato).

The instructor should show the students didactic keys and define their

functions (they are used to show the techniques of identifying plants and animals).

Students can then work in groups to:

- Identify a few groups of plants (or animals) with the help of didactic keys.
- Identify a selected group of plants or animals.
- Determine the accuracy of their work by comparing their answers with illustrations.

For homework, the teacher can suggest preparing an answer to the question: How can you establish the name of a plant or animal that you do not know? Those particularly interested in biology or willing to do additional homework can identify other plants on the basis of the key and bring in the specimens for the next lesson.

Phylogeny: The Relationship Between Taxonomy & Evolution

Developed by
Jon Fiorella

Taxonomy helps us to investigate the past. The similarities of organisms alive today can be used to infer evolutionary relationships and can tell us a lot about their evolution from earlier forms. In most cases, organisms that are most similar in their present forms are most closely related in an evolutionary sense. A diagram of these relationships is called a "phylogenetic tree." The purpose of this lab is to give the student the opportunity to gain experience in classifying and to show the relationship between taxonomy and evolution. In small groups, students will develop phylogenetic trees to show the evolutionary relatedness of common household hardware "organisms."

MATERIALS

Packets of common household hardware. These packets should all be the same and should include such things as screws, nails, tacks and fasteners. Ziploc® plastic bags can be used and are obtainable at any supermarket. Paper bags also work well and can be held closed with clothespins or paper clips. Paper bags have the added advantage of preventing the students from seeing the contents until the appropriate moment.

PROCEDURE FOR THE TEACHER

Before Lab: The teacher should organize the packets so that each has the same pieces (20-25) of hardware. Each group of four students should receive one packet.

Day of Lab: The teacher should explain the lab in such a way that the students realize that there is no one "right" answer. The critical thinking processes and the ability to justify the classification pattern should be emphasized. It is very common for students to disagree among themselves so they must be prepared to compromise. Looking at another group's work will not be useful as the other group may be using a different system of classifying.

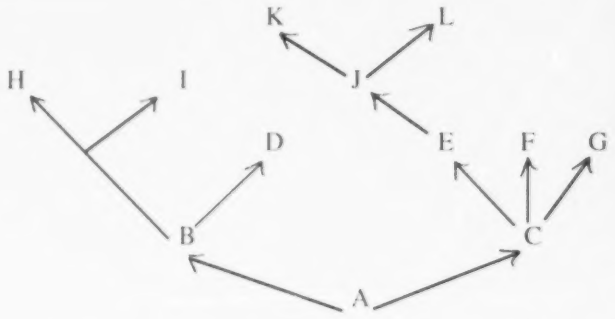
PROCEDURE FOR THE STUDENT

1. Study the packet of household hardware and arrange the pieces into groups of similar objects. The groups should be organized based on the structure of each piece and not on its function. Form at least two or three groups.

2. For each piece of hardware, make a list of three characteristics that you could use to classify it (e.g. thin stem, flat head, silver, threaded, etc.).

3. Now pretend that these are living organisms. For each group, decide which organism seems to be the simplest. Which one is the most advanced? Make an arrangement of the pieces to show how these organisms may have evolved from the simplest to the most advanced forms. Is there one "organism" that could belong to all the groups? This would be the ancestor of all the others. Be aware that you are creating a "tree" of evolutionary relationships so it is necessary to show branching (two or more organisms

can evolve from the same ancestor). Your classification scheme may also include extinct organisms.



4. After you have arranged the organisms into an evolutionary tree, draw them. You do not have to be an artist to do this, but you must be careful to include the essential details of each organism in your drawings.

HELPFUL HINTS

1. This lab exercise will show a relationship between taxonomy and evolution. You may use it as an introduction or as a summary if you have already covered the higher concepts necessary.

2. Be prepared for lively discussion while the students are trying to come up with a pattern that they can all agree on.

3. Groups of 3-4 students seem to work best. In larger groups, some people get left out of the process and in smaller groups, they tend to come to an agreement too soon.

4. Encourage them to consider branching. Too often students tend to classify in a linear fashion only.

5. When you review this lab, have the different groups compare their results. Even though all the groups used identical packets, many different classification schemes resulted. Encourage them to justify the logic they used. It may have been necessary to use more than three characteristics to classify each piece of hardware. Point out that scientists sometimes disagree on schemes of classification and the more information at their disposal, the more accurately they tend to classify.

An example of this is the question over the classification of the giant panda. Originally this panda was grouped with the bears, but there was dispute that it might be more closely related to the lesser panda, which belongs to the raccoon family. After detailed studies of their anatomies were performed, it was decided that the giant pandas were more closely related to the bears.

This conclusion was later verified with studies of their DNA and proteins (Curtis & Barnes 1989).

6. Advanced classes can carry this lab further by developing an actual classification scheme from phylum to species. A key can be created for the purpose of classifying any new pieces of hardware that might be "discovered" later.

7. Nails, screws and tacks can be sharp!! Remind students to treat these "organisms" with respect.

8. Use a variety of sizes of hardware, but select relatively large items. Very small pieces are harder to handle and get lost easily.

SUMMING UP

You may want to use the following questions as a part of the lab summary:

1. What basis did you use in classifying your organisms?
2. How did you decide which organisms were most primitive?
   Could they have actually been the most advanced? Why or why not?
3. How did you decide which organisms were most advanced?
4. What does the science of taxonomy tell us about evolution?
5. Why do different groups have different phylogenetic trees?
6. Which organisms on your evolutionary tree are extinct?
   How do you know this?
7. Which organisms are the most closely related?
   Which are most distantly related?

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Confusing Cats: *The Florida Panther*

Developed by the Biological Sciences Curriculum Study (BSCS)

Does the species concept have any significance beyond the specialized interests of biologists? Consider the case of the Florida panther, *Felis concolor coryi*.

The Florida panther is an endangered species. Thousands of these swift, powerful predators once roamed the southern portion of North America. Now, however, because of human development of the panther habitat, fewer than 50 individuals remain. They are restricted to a few small areas south of Florida's Lake Okeechobee. Locate the Everglades and Big Cypress Swamp on a map of the United States. The remaining Florida panthers are found in those areas and on some private lands as well.

Because the panther population is so small, there has been a large amount of inbreeding. What impact might this have on the survival of the Florida panther?

[Review with the students the genetic consequences of inbreeding. Inbreeding has resulted in an increase in some genetic abnormalities among the panthers. For example, many of the cats have a kinked tail. More important, about 90 percent of the sperm in male panthers is defective which, of course, further impairs the ability to increase the number of panthers in a population.]

Because there are so few panthers left, *F. concolor coryi* is protected by the U.S. Endangered Species Act of 1973. This means that no one can hunt the cats and that their habitat is protected against development. Nevertheless, some people would like to develop parts of the panthers' range.

Biologists classify the Florida panther as a subspecies, one of 27 subspecies of cougars—*Felis concolor* —in the western hemisphere. There are 14 subspecies in North America. These big cats also are known as mountain lions or pumas in some parts of their range. Subspecies are a protected classification under the U.S. Endangered Species Act. The other protected classifications are species and populations. Some recent research, however, has raised questions about the classification of *F. concolor coryi* as a subspecies. The answers to these questions may have a direct impact on whether this particular panther remains in the protected category or becomes subjected to pressures that may drive it to extinction.

[Some students might wish to investigate the differences between subspecies of cougars, concentrating on adaptations to different environments in the western hemisphere.]

In 1990, molecular geneticist Stephen O'Brien and veterinarian Melody Roelke studied the genetics of the following cougars:

- *F. concolor coryi*
- Eight other subspecies from North America

• Three subspecies from South America.

They also studied the genetics of captive panthers from a population known as the "Piper stock." This population began with a litter of cats born to a female in the Big Cypress Swamp in the 1940s. During the next 20 years, several other captive cats were added to this population. These new cougars, according to O'Brien and Roelke, "were from outside the range of the Florida panther" (O'Brien, et al. 1990).

ABOUT THE STUDY

1. Drs. O'Brien and Roelke examined mitochondrial DNA (mtDNA) and a specific enzyme called "APRT." There are two forms of APRT, simply called A and B. The forms are determined by different alleles. Tables 1 and 2 summarize the results of the enzyme and DNA analysis. What can you conclude from the data?

[Remind the students that enzymes are gene products. Enzyme variants result from different alleles. Adenosine phosphoribosyl transferase (APRT) helps to recycle nucleotides in the cell; this information is not essential to the problem at hand, but students might want to know the function of the enzyme. O'Brien and Roelke analyzed the mtDNA using restriction fragment length polymorphisms (RFLPs). It is not necessary to explain this process in detail for the students. For those who are interested, you can consult any modern textbook of genetics. The Biological Sciences Curriculum Study (BSCS) high school program Advances in Genetic Technology *(1989), published by DC Heath Company, contains two activities that explain RFLPs. If your students have not been exposed to the fact that mitochondria have their own DNA, you should discuss this issue briefly.*

It might be necessary to help your students interpret the data shown in the tables. First, direct them to Table 1, column 3, "Type of APRT Enzyme." They should note that APRT-B, which appears in the Florida panther populations, only appears elsewhere in a South American population. Next, direct them to Table 1, column 5, "Type of mtDNA," and Table 2, which show the high degree of similarity between the B mtDNA in the Florida panther populations and the E and F mtDNA of the South American populations. These data suggest that, for the enzyme and mtDNA examined, the Florida panther populations share more genetic characteristics with the South American populations than with other North American populations.]

2. Propose a hypothesis to explain the data. How might you test your hypothesis?

[The most likely hypothesis is that South American cats were introduced into the Florida panther populations at some point. A test of this hypothesis requires proof that such an introduction occurred, and there is, in fact,

Location	Subspecies	Type of APRT Enzyme	Individuals	Type of mtDNA	Individuals
FLORIDA PANTHER POPULATIONS					
Big Cypress	*coryi*	A, B	24	A, B	25
Everglades	*coryi*	A, B	7	B	7
Piper captive stock	?	A, B	10	A	7
NORTH AMERICAN COUGAR POPULATIONS					
Texas	*stanleyana*	A	12	C	3
Colorado	*hippolestes*	A	3	C	3
Arizona	*azteca*	A	4	C	1
Nevada, Utah	*kaibabensa*	A	2	C	1
Arizona	*browni*	A	2	C	1
California	*californicz*	A	4	—	—
Southwest Oregon	*oregonensu*	A	5	C	1
East Oregon	*missoulensu*	A	1	D	1
SOUTH AMERICAN COUGAR POPULATIONS					
Northern Chile	*puma*	A, B	10	E, F	5
Central Chile	*araucanus*	A	2	E	2
Southern Chile	*patagonicz*	A	3	E	6

From *National Geographic Research* 6(4): 487. © 1990. Adapted by permission.

Table 1. Results of genetic tests on Cougar (*Felis concolor*) subspecies.

supporting evidence. Science *reports: "Archives of the Everglades park revealed that a local menagerie had released captive cougars in the late 1950s and 1960s, with the permission of the Park Service, under the impression that they were all Florida panthers" (Fergus 1991). O'Brien and Roelke state: "The origin of the Everglades pumas with the B mtDNA haplotype and the APRT-B alleles is not obvious, but a likely candidate would be the captive Piper stock. The Piper stock and the Everglades pumas both have a high frequency of APRT-B, an allele not found anywhere else*

in North America, but seen in a limited sample from South America. Furthermore, releases have been documented of seven Piper animals (including three females) into the Everglades National Park between 1957 and 1967..." (O'Brien, et al.1990).

Another hypothesis to explain the genetic differences involves the establishment of two distinct panther populations as a result of genetic bottlenecks and the founder effect. Some students may have sufficient background in genetics to propose this hypothesis. O'Brien, Roelke and their colleagues do not think this hypothesis is valid, however. Their rather complex reasons are elaborated in the original paper, which is cited in the references at the end of this activity.]

3. If your hypothesis is correct, how might that benefit the Florida panther?

[The population clearly suffers from a lack of genetic variation (recall the information about inbreeding). The introduction of foreign genetic material may help improve the viability of the populations.]

mtDNA Type	Similarity to mtDNA Type B
A (North American)	low
C (North American)	low
D (North American)	low
E (South American)	high
F (South American)	high

Table 2. Similarities of mtDNA type B to other mtDNA types.

4. The genetic data indicate that the Florida panther is actually a genetic hybrid, carrying genes from different subspecies. The U.S. government, it is important to note, has rules that hybrids are not protected under the Endangered Species Act.

In 1990, state farm bureaus from Idaho, Montana and Wyoming used this ruling to try to remove the gray wolf (*Canis lupus*) from the endangered species list. Biologists have shown that the gray wolf, which often kills livestock in the three states, carries genes from the coyote. This means the two animals are interbreeding and producing hybrids. Removal of *C. lupus* from the endangered species list would mean that ranchers could hunt the wolf and reduce the threat to their herds.

What impact might the new genetic data provided by Drs. O'Brien and Roelke have on the survival of the Florida panther?

[If hybrids are not protected, the panther's habitat might be subject to development. The Science *article concludes that removal of* F. concolor coryi *from the endangered species list likely will result in the extinction of this subspecies.]*

5. The fate of *F. concolor coryi* depends on biological classification— in this case, whether the Florida panther is classified as a hybrid. The U.S. Fish and Wildlife Service, which runs the endangered species program, is not trying to decide what is and is not a hybrid. What have you learned about the definition of a species from your study of evolution and classification?

[Species can be defined as groups of interbreeding populations that are reproductively isolated from other such groups. The evolutionary biologist Ernst Mayr first proposed this biological species concept in 1940. The concept recognizes that hybrids between species will arise occasionally. In general, however, reproductive isolation tends to protect the genetic purity of the species.]

6. Subspecies are restricted to a particular range or habitat, and they share some traits that distinguish them from other subpopulations of the species. Because they are below the species level, subspecies can easily reproduce. Government policy does not protect hybrids between species. Consider the definition of a species and explain whether you think that policy is sound or unsound.

[Let the students express their opinions freely, but be certain to focus on the biological justifications. The hybrid policy as written may help protect the integrity of endangered species. For example, it discourages the production of hybrids in captivity and the introduction of a species into a habitat occupied by a closely related species where hybridization might occur.]

7. Should government policy protect hybrids between subspecies? Remember to consider the biological definition of a subspecies as you explain your position.

[Subspecies interbreed naturally because they are below the species level. O'Brien and Mayr (1991) note that because such "mixed subspecies [may] acquire unique characteristics, they represent important components of biological diversity."]

8. Should the Florida panther be protected? Provide sound biological justifications for your position.

[Accept any position that is well supported by the biology. Conclude the discussion by highlighting the following points:
• *Systems of biological classification are human constructs. We develop*

them to suit our purposes and to reflect our current views of life on Earth.
- *Systems of biological classification can and do change.*
- *Public policy implications and important decisions often follow from our knowledge of science.]*

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Evolution Theory: *Genetic Technology in Basic Research*

Developed by the Biological Sciences Curriculum Study (BSCS)

FOCUS

This activity allows students to see how researchers use genetic technology to investigate basic biologic problems.

OBJECTIVES

Students will have an opportunity to:

1. Use a model of DNA hybridization to investigate the degree of relatedness of three organisms (chimpanzee, human and gorilla).

2. Explore how a tool such as DNA hybridization is used to study other questions in evolutionary biology.

SUGGESTED SCHEDULING

Average preparation time for this activity = 80 minutes.
Average time required to cover this activity the first time = 58 minutes.

MATERIALS (per team of four)

- Paper clips: 35 each of black, white, green and red

BACKGROUND FOR THE TEACHER

Point out to your students that this investigation only demonstrates how DNA hybridization *can* be used. The data students accumulate when using this model are *not* to be taken as actual support for one hypothesis or another. Questions raised in this investigation are still very active matters for debate in the biological sciences. Students should not be led to believe that the data in this activity are definitive.

Students might be interested in the process by which complementary DNA (cDNA) is synthesized. It is roughly as follows: messenger RNA (mRNA) for the gene in question (in this case, hemoglobin) is isolated; the mRNA then is exposed in culture to activated nucleotides and the enzyme reverse transcriptase. (Reverse transcriptase reverses the normal process of transcription so that DNA is synthesized from an RNA template, rather than the other way around.) The mRNA is dissolved, leaving the single strand of new DNA; that DNA then is exposed to DNA polymerase, which synthesizes a new DNA strand that is complementary to the original gene for the protein in question. The 20-base sequence used in this activity is not actually a part of the hemoglobin gene. Hemoglobin mRNA is often used in such studies, however, and is readily available in immature red blood cells. If your students are interested, they can consult the article by Miyamoto et al. (see reference on page 86) for a detailed, base-by-base comparison of a portion of the hemoglobin genes for human, chimpanzee, gorilla and orangutan.

Have students work in teams of four. Each student will "synthesize" one strand of DNA or cDNA. To save time, make sure all strands are synthesized

simultaneously. Have students follow the directions for hybridizing (matching). Reinforce the notion that this is a model.

BACKGROUND FOR THE STUDENT

Biological classification is the process by which biologists assign organisms to specific groups. The group may be as large and encompassing as a kingdom, such as animalia, or as small and limiting as a species, such as *Homo sapiens*—the species to which humans are assigned.

Classification is not merely a method of assigning organisms to groups so that biologists can keep track of them. The groups to which organisms are assigned also imply the degree of relatedness between those organisms. Organisms that share smaller groups of classification are more closely related than are organisms that share only large groups.

Table 1. Classification of Four Organisms.

	Human	Gorilla	Frog	Katydid
Phylum	Chordata	Chordata	Chordata	Arthropoda
Subphylum	Vertebrata	Vertebrata	Vertebrata	
Class	Mammalia	Mammalia	Amphibia	Insecta
Subclass	Eutheria	Eutheria		
Order	Primates	Primates	Salientia	Orthoptera
Suborder	Anthropoidea	Anthropoidea		
Family	Hominidae	Pongidae	Ranidae	Tettigoniidae
Subfamily			Ranidae	
Genus	*Homo*	*Gorilla*	*Rana*	*Scudderia*
Species	*Homo sapiens*	*Gorilla gorilla*	*Rana pipiens*	*Scudderia Furcata*
Subspecies			*Rana pipiens sphenocephala*	*Scudderia furcata furcata*

Until the mid 1970's, classification was based largely on the comparison of observable structures in a given organism. For example, taxonomists might compare the structure of forelimbs in mammals. In recent years, they also have been able to compare the structure of certain proteins.

Modern research techniques allow biologists to compare the DNA that codes for certain proteins and to make predictions about the relatedness of the organisms from which the DNA was taken. This investigation shows you a model of that technology. It might be helpful for you to review the relationship between DNA and proteins.

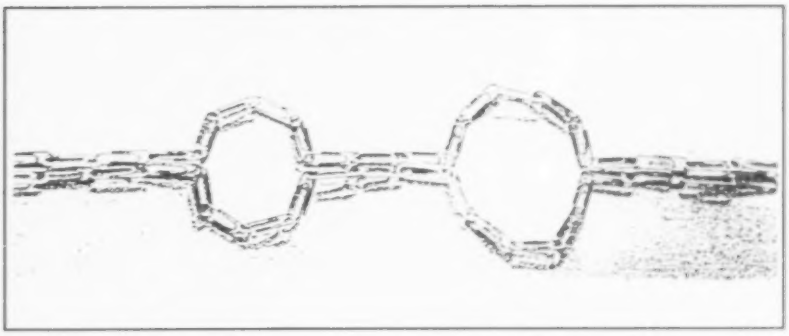

Figure 1. Pairing and loops of complementary DNA strands.

PART A: COMPARING DNA STRANDS

PROCEDURE

1. Based on the information in Table 1, which organisms share the most groupings?
Answer: Human and gorilla share the most groupings.

2. On the basis of the data in Table 1, which organisms are least closely related?
Answer: Katydid is least closely related to the others in Table 1.

3. Working in teams of four, "synthesize" the DNA strands as follows. Allow the paper clips to represent the four bases of DNA according to the following key: black = adenine (A), white = thymine (T), green = guanine (G), red = cytosine (C).

Synthesize DNA strands by hooking together paper clips of the appropriate colors. Stretch the string of paper clips out on the lab table with Position 1 on the left. Label a small piece of paper as indicated and hook it to the Position 1 paper clip. Each strand will represent a small section (20 bases) of a gene that codes for a protein hemoglobin.

4. Team Member 1: Synthesize the following piece of DNA by hooking together paper clips in this sequence:

Position 1 Position 20
A–G–G–C–A–T–A–A–A–C–C–A–A–C–C–G–A–T–T–A

Label the strand "human DNA." This will represent a small section (20 bases) of the gene that codes for the protein hemoglobin in humans.

5. Team Member 2: Synthesize the following strand:
Position 1 Position 20
T–C–C–G–G–G–G–A–A–G–G–T–T–G–G–C–T–A–A–T

Label this strand "chimpanzee cDNA." cDNA stands for complementary DNA. cDNA is a single strand of DNA that will match up with its partner strand. Remember, the bases in DNA are complementary. That is, adenine (A) will always pair with thymine (T), and cytosine (C) will always pair with guanine (G). This cDNA was made from the gene that codes for chimpanzee hemoglobin.

6. Team Member 3: Synthesize the following piece of cDNA:

Position 1 Position 20
T–C–C–G–G–G–G–A–A–G–G–T–T–G–G–T–C–C–G–G

Label this strand "gorilla cDNA." This cDNA strand was made from the gene that codes for gorilla hemoglobin.

7. Team Member 4: Synthesize the following piece of DNA:

Position 1 Position 20
A–G–G–C–C–G–G–C–T–C–C–A–A–C–C–A–G–G–C–C

Label this strand "hypothetical common ancestor DNA." You will use this strand in the second part of this activity.

8. Compare the sequences of the human DNA and the chimpanzee cDNA. Match the human DNA and the chimpanzee cDNA base by base (paper clip by paper clip). Remember, black (adenine) must always pair with white (thymine), and green (guanine) must always pair with red (cytosine). If the bases are complementary (that is, if the colors match correctly), allow the clips to remain touching, as shown in Figure 1. If the bases are not complementary, separate the clips slightly to form a loop, as shown in the figure. Count the number of loops. Also count the total number of bases that do not match. Record the data in the appropriate columns in Table 2a.

Table 2a. Hybridization data.

Human DNA Hybridized to:	Chimpanzee cDNA	Gorilla cDNA
Number of loops		
Number of differences		

9. Repeat step 8, using the gorilla cDNA and the human DNA. Enter the data in the appropriate columns in Table 2a.

DISCUSSION

1. Based on the data you have collected for this one protein, is the gorilla gene or the chimpanzee gene more similar to the human gene?
Answer: Based on the data collected, the chimpanzee gene is more similar to the human gene than is the gorilla gene. Table 2b below represents data that students should have recorded in 2a.

2. Again, based on the data you have collected for this one protein, does the gorilla or the chimpanzee seem more closely related to humans?
Answer: Based on the data collected, the chimpanzee seems more closely related to humans than does the gorilla.

3. Do the data prove that your answer to question 2 is correct? Why or why not?
Answer: The data do not prove anything; they simply lend support to the hypothesis that the chimpanzee is more closely related to humans than is the gorilla.

4. How might you provide additional support for the hypothesis you proposed in your answer to question 2?
Answer: One could produce additional data by using DNA from other proteins or by comparing data from the fossil record.

Table 2b. Hybridization data — For the teacher.

Human DNA Hybridized to:	Chimpanzee cDNA	Gorilla cDNA
Number of loops	1	2
Number of differences	5	10

EXTENSION

Mitochondria have their own DNA. Unlike nuclear DNA, however, mitochondrial DNA (mtDNA) does not come from both parents. Although sperm do contain mitochondria that provide energy for locomotion, the mitochondria are not contained in the portion of the sperm that penetrates the ovum during fertilization.

An ovum contains numerous mitochondria, which are replicated in the fertilized egg and passed on to all descendant cells during development of

the fetus. Therefore, all mitochondria, whether one is male or female, are maternally derived.

The maternal transmission of mtDNA in humans has continued since the beginning of the species. In fact, because mtDNA is transmitted only through females, it is theoretically possible to trace the origin of mtDNA to one of several females who were the first members of a species that was not fully human. But how long ago did that species live? To answer that question, one needs some indication of the variety in mtDNA that mutates to produce those changes. If those data are available, one can use mtDNA as a sort of "molecular clock" to tell evolutionary time.

Molecular biologists know that mtDNA "accumulates mutations at a much higher rate — five to 10 times faster — than does nuclear DNA," according to an October 1987 article in *Science* (see References). That makes mtDNA a good clock for measuring short time spans in evolutionary time, that is, time spans measured in hundreds of thousands of years rather than millions of years.

Molecular biologists at the University of California, Berkeley, used restriction enzymes to "chop up the mtDNA from 21 individuals from diverse geographic and racial backgrounds." They then measured the amount of variation in the fragments (RFLPs) that resulted. That data, combined with the information about how fast mtDNA accumulates mutations, led the researchers to conclude that it would have taken between 180,000 and 360,000 years for modern humans to have accumulated that amount of variation from one ancestral female. The biologists also concluded from their data that the ancestors of modern humans originated in Africa.

Other biologists question those data and the conclusion derived from them. They contend, for example, that mtDNA accumulates mutations more slowly than the Berkeley group maintains. This means that it would have taken much longer for the amount of variation in modern mtDNA to accumulate and that ancestral humans may have lived about 500,000 years ago.

Obviously, there are still many questions to be answered about a potential "mitochondrial Eve." Most important is the relationship of that hypothetical individual to the evolution of anatomically modern humans. This problem is complicated by the fact that mtDNA is really not involved in the formation of new species because it is not part of the nuclear DNA that is subject to the pressures of natural selection.

Use the foregoing information to discuss with students the ways in which advances in technology allow new approaches to old problems, in this case,

human evolution. Note as well the disagreements about the rate at which mtDNA accumulates mutations. Such disagreements are central to the process of science.

PART B: AN EVOLUTIONARY PUZZLE

Discuss the persistent nature of debates in evolutionary biology and in science in general. Continuous questioning and revision are central to scientific investigation and distinguish science from other ways of knowing, such as religion.

Evolutionary biologists often disagree about the tempo of evolutionary change and about the exact nature of speciation and divergence. Review briefly the debate described for students in this part of the activity. Reinforce the notion that they will use a model and hypothetical data to examine the problems.

PROCEDURE

Biologists have determined that mutations in DNA occur at a regular rate. They can use this rate as a "molecular clock" to predict how long ago in evolutionary history two organisms began to separate from a common ancestor. In this part of the activity, you will use your paper clip model to provide data to support one of two hypotheses about a common ancestor for humans, chimpanzees and gorillas.

1. Read the following information about a current debate among scientists who study human evolution:
Most scientists agree that humans, gorillas and chimpanzees shared a common ancestor at one time in evolutionary history. However, one group thinks the fossil record shows that gorillas, chimpanzees and humans split from one common ancestor at the same time (seeFigure 2).

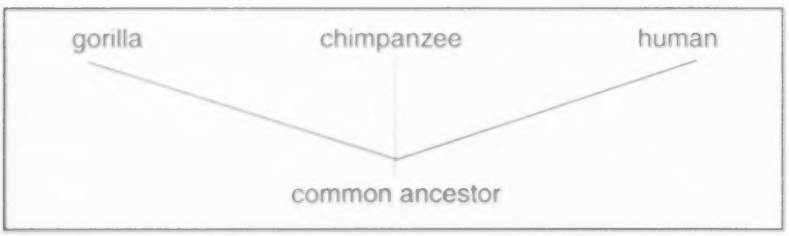

Figure 2. A model for the split from one common ancestor.

A second group thinks the fossil record shows that there were two splits. In the first, gorillas split from the common ancestor. Humans and chimpanzees

then shared another common ancestor for perhaps two million years. They then split again and evolved into their present states (see Figure 3).

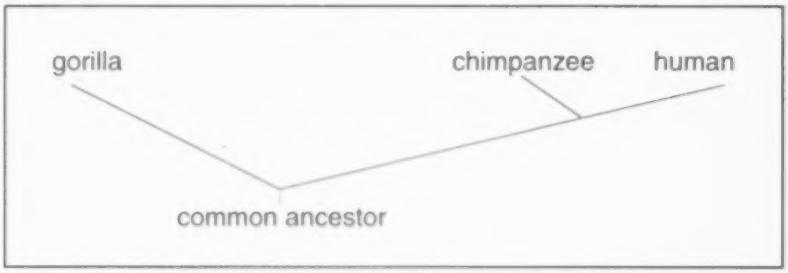

Figure 3. A model for a pattern of splitting which involves two splits.

2. Use your DNA model and the DNA sequences from Part A to investigate this debate. First, use your human DNA as a guide to synthesize a human cDNA. Do that as a team. Make certain that the human cDNA is complementary to the human DNA strand.

3. Assume that the hypothetical common ancestor DNA you synthesized jn Part A is DNA for hemoglobin extracted from a hypothetical common ancestor. Now, match all three samples of cDNA (gorilla, human and chimpanzee) with the common ancestor DNA, one sample at a time. Allow the paper clips to touch where the bases match correctly; form loops where the bases do not match. Record your data in Table 3a.

Table 3a. Hybridization data: Common ancestor.

Common Ancestor DNA Hybridized to:	Human cDNA	Chimpanzee cDNA	Gorilla cDNA
Number of loops			
Number of differences			

DISCUSSION

1. Which cDNA is most similar to the common ancestor DNA?
Answer: Gorilla cDNA is most similar to common ancestor DNA. Table 3b represents data students should have recorded in Table 3a.

2. When matched to the common ancestor DNA, which two cDNAs showed the most similar patterns?

Table 3b. Hybridization data: Common ancestor — For the teacher.			
Common Ancestor DNA Hybridized to:	Human cDNA	Chimpanzee cDNA	Gorilla cDNA
Number of loops	2	2	1
Number of differences	10	8	3

Answer: Human cDNA and chimpanzee cDNA have the most similar patterns when hybridized to the common ancestor DNA.

3. Which model in the evolutionary debate described earlier does your data support?
Answer: The data show two separate divergences, rather than a single, three-way split. This supports the hypothesis shown in Figure 3.

4. Do your findings prove that this model is the correct one? Why or why not?
Answer: The findings using this model do not prove the validity of the hypothesis, but they do provide some direction for additional research, such as comparing the genes for other proteins or expanding the search for fossils that can shed more light on the likely pattern of divergence. Remind students that they have been using a model and hypothetical data, most especially the common ancestor DNA. No such DNA yet exists.

BUILDING CONCEPTS

Review the following concepts:

- All organisms contain nucleic acid.
- The genetic code is a universal language.
- We can measure the evolutionary relatedness of two organisms by comparing their DNA; greater variation indicates more distant relationship.
- Genetic technology is a powerful research tool that has improved our understanding of basic biological principles.

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Credits:

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